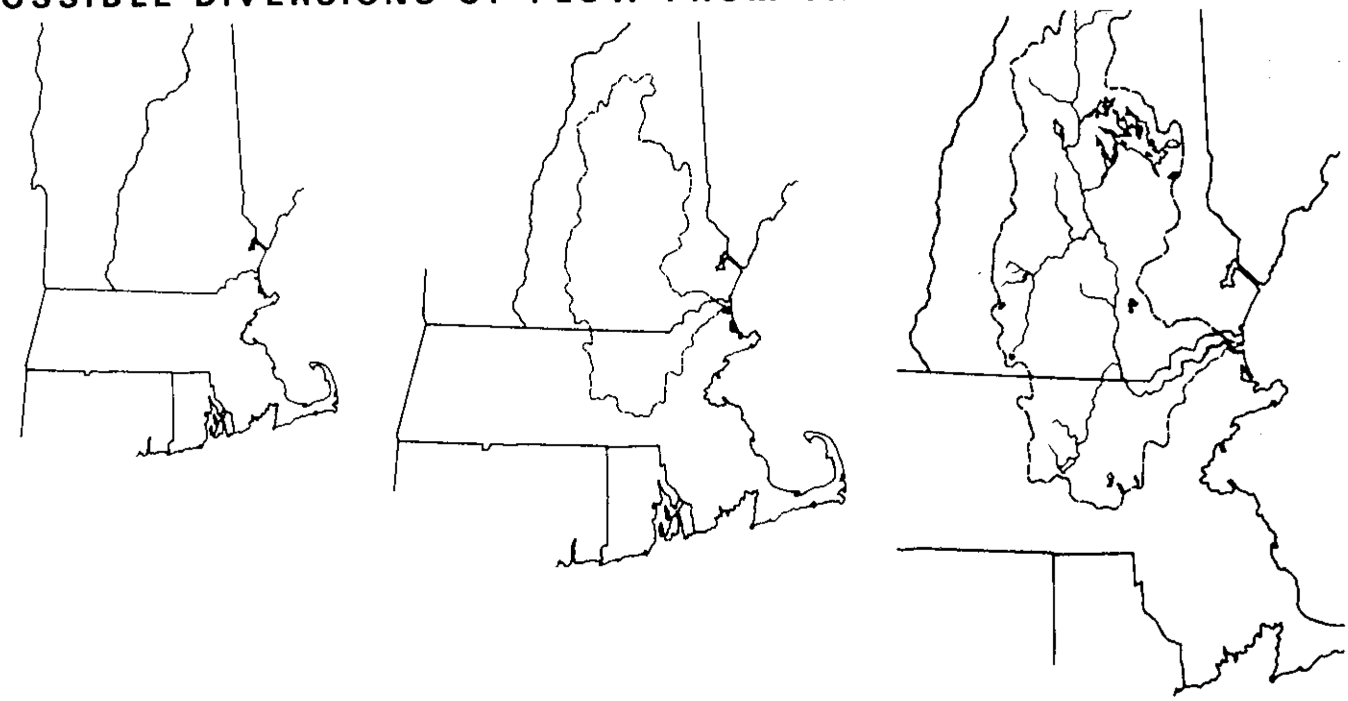
NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

MERRIMACK RIVER BASIN WATER SUPPLY STUDY

AN INVESTIGATION OF SOME ENVIRONMENTAL IMPACTS FOR POSSIBLE DIVERSIONS OF FLOW FROM THE MERRIMACK RIVER



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AN INVESTIGATION OF SOME ENVIRONMENTAL IMPACTS FOR POSSIBLE DIVERSIONS OF FLOW FROM THE MERRIMACK RIVER

FOR

DEPARTMENT OF THE ARMY

NEW ENGLAND DIVISION, CORPS OF ENGINEERS

IN COMPLIANCE WITH

CONTRACT NO.: DACW 33-74-C-0140

PREPARED BY:

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WELLESLEY HILLS, MASSACHUSETTS

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1.0 INTRODUCTION

1.1 Objectives

This report assesses some of the physical, ecological and socio-economic impacts of a possible diversion of water from the Merrimack River for future water supply purposes on the potential anadromous fish restoration program. These impacts are then compared with the effects of naturally occurring impediments to anadromous fish restoration, including dams, flow requirements for power generation, pollution and historical low flows. The study also considers some of the more important physical impacts which would be related to flow modification through large water supply diversions and the socio-economic impacts (recreation, commercial fishery, aesthetics) of a successful anadromous fish restoration program.

During the colonial and early national periods the Merrimack River and its tributaries provided extensive fisheries for anadromous fish species including salmon, shad, striped bass, bluebacked herring, alewives, sturgeon, and smelt. Damming of upstream tributaries practically eliminated the salmon fishery early in the 19th century. Construction of dams across the mainstem at Lawrence and Lowell, coupled with industrial pollution, essentially eliminated the shad and other important fisheries by the end of the 19th century, in spite of extensive efforts conducted by Massachusetts to maintain fishways and to provide a base population through stocking. While it is possible that all anadromous species formerly found in the system might be reintroduced, current plans are concentrating upon restoration of the salmon and shad fisheries. Analysis of habitat and spawning ground availability suggest that once adequate fishways have been constructed and a stocking program has been carried out, it will be possible to maintain annual runs of about 11,000 salmon and 1,000,000 shad.

1.2 Area of Study

The area of study is the Merrimack River mainstream, in southern New Hampshire and Massachusetts, between the river's mouth and the upper limits of the Pawtucket Dam pool, a total distance of 59 miles. Three reaches or segments of the river were considered in the study: the entire dam pool above Pawtucket Dam (22.5 miles); the river and dam pool between the Pawtucket Dam in Lowell and the Essex Dam in Lawrence (7.5 miles); and the river and estuary between the Essex Dam and the river mouth at Newburyport (29 miles). A small portion of the upper reach extends into New Hampshire; the rest of the study area lies within Massachusetts.

1.3 Scope of Study

The analysis and evaluation of impacts consists of data collection related to the physical characteristics of the Merrimack River, its importance as a component in the local environment and its use as a recreation resource. Next, the potential anadromous fishery in the river was examined in terms of species known to have been present in the past, restorable species, planned restoration programs, and the economic importance of a revived fishery.

Determination of base flow requirements to meet the needs of restored anadromous fish species during migration, breeding, and residence in the river was accomplished with special emphasis on flow rate maintenance for operation of fishways, for habitat support, and for purposes of up-and downstream migration. Finally, diversion studies were carried out at seven rates of water removal (between 100 and 2,000 cfs) to establish limits on diversion by month for years characterized by average, high, and low flow. Base flow requirements for anadromous fish earlier provided the cut-off point for diversion in any month.

2.0 SUMMARY

2.1 Impact Assessment and Evaluation Framework

The framework for an impact analysis of potential water supply diversions from the Merrimack River on the planned restoration of anadromous fish runs requires that data be collected and impacts assessed with respect to the effects that flow regulation and modification would have on the primary physical and ecological characteristics of the Merrimack River which are shown to be related directly to the maintenance of a viable anadromous fishery.

A key feature of this assessment is the ability to abstract essential environmental indicators, parameters and criteria of a quantitative and qualitative nature, based upon a knowledge of the physical environmental requirements of anadromous fish, to enable a knowledgeable projection of the potential for success of such a restoration program. Choice of environmental parameters and indicators are founded upon the basic concept that water supply diversion from the Merrimack River constitutes an action of flow modification with primary and secondary consequences on an interacting tri-component system in the river and estuary.

The three basic components of the systems are the existing physico-chemical system, the biota and the sphere of human activities superimposed upon the natural system. Among the human activities or externalities which presently affect the river's physico-chemical system and biota are: land use modifications contributing to point and non-point pollution sources; anticipated measures for point source pollution control by 1985; upstream power cooling requirements; hydroelectric power requirements, dams, recreation and high flow skimming and river diversions.

Among the most easily identifiable and measurable parameters of the physical system are: hydrology (flow volume, magnitudes and duration of extremes), salinity, tides, flushing or residence time of wastes in a system and waste assimilation capacity of the river and estuary, and meteorological effects. Physico-chemical indicators which may be used to characterize effects and impacts on the resident biota include: temperature, biochemical oxygen demand, dissolved oxygen, salinity, turbidity, total dissolved solids, heavy metals, pesticides, etc.

Ultimately the physico-chemical system and the superimposed human sphere of activities impact the aquatic biota, influencing such characteristics as: timing of fish runs, seasonal migration patterns, availability of spawning areas, food web interdependence, temporal, and spatial distribution of key anadromous and resident fish species and ecosystem rebound capabilities after extreme natural events such as droughts, hurricanes, and extreme pollution.

Essential environmental indicators, parameters and criteria should be abstracted in such a way as to readily demonstrate cause and effect relationships between flow modifications and the interacting tri-component river-estuary ecosystem.

2.2 The River

For the purposes of this study the Merrimack is divided into three reaches by two major dams; the Pawtucket Dam at Lowell, Massachusetts, and the Essex Dam at Lawrence, Massachusetts. The river is fed by numerous small streams and four major tributaries within the three reaches studied. Analysis of gage data was accomplished to provide flow-duration data on a month-by-month basis for years of high, average, and low flow. It was found that, for the most part, there was little variation in discharge from one reach to another. Water quality data from recent observations were also analyzed. While water quality did not differ greatly from one reach to another, it tended to be poorer in the lower reach, which includes the estuary and mouth. Certain water quality parameters, notably sediment concentration and sediment discharge, were found to be closely related to discharge rate. Water temperatures, levels of dissolved oxygen, and concentrations of chlorophyll A were found to be more strongly influenced by seasonal climatic conditions than by river stage. Finally, it was found that a number of water quality parameters showed no definite correlation with discharge. The implications of observed variation in the several classes of water quality parameters for restoration and maintenance of an anadromous fishery were noted, as was the impact on such a fishery of planned improvements in water quality.

Analysis of related environmental resources and issues showed that, in general, these were largely independent of discharge. Wetlands in the tidal portion of the river are dependent on tidal flow rather than river flow. Very few truly riverine wetlands are found in the inland reaches of the river. Most of the inland wetlands encountered are at significantly higher elevations than their points of discharge into the Merrimack, indicating their independence of river stage. The few found which could be influenced by river stage occur in reaches of the River where the water level is relatively stable. Flood control works provide protection against flooding, though there is a possibility that some limited new construction may take place with the 100-year floodplain. Navigation by pleasure boat is affected slightly by changes in river stage; spring freshets help to scour the bed of sediment deposited there during periods of low flow. Withdrawals for municipal water supply do not currently represent a major requirement and even by 2020 are expected to amount to only 110 cfs in the Massachusetts section of the Merrimack.

2.3 Anadromous Fish

The Technical Committee for Fisheries Management of the Merrimack River Basin has carried out studies of anadromous fish habitat requirements and spawning ground availability and has suggested that once adequate fishways over the dams have been constructed and a stocking program has been carried out, it will be possible to maintain annual runs of about 11,000 salmon and 1,000,000 shad. Maintenance of the run will require water quality as good as or better than that now found in the Merrimack. This requirement, along with that to maintain flow through the fishways, sets limits on diversion volumes during certain months. Present evidence of improved future water quality, based on theoretical modeling of key water quality parameters designed to determine whether water quality objectives set by the Environmental Protection Agency for 1983 and 1985 effluent standards would be met, supports the contention that dissolved oxygen (DO), which is the key parameter for anadromous fish restoration, will improve substantially. Among the more critical elements to consider in anadromous fish restoration are: the diversion rights of power companies along the river for hydropower generation; the physical need for at least 3,500 cfs flow over the dams in order for fish ladders to operate effectively despite the fact that natural low flows fall well below that figure during summer months; the lack of turnover in the pools which form behind the dams during low flow periods and the depressed oxygen levels throughout most of the water column; the effects of droughts of severe magnitude and duration on successful restoration and the ability of the resident ecosystem to rebound after such severe occurrences; the effect of flow modifications on spring freshets which are considered necessary as a mechanism for triggering migrations; avoidance of water intake inlet speeds in excess of river current speeds during periods of down migration; and proper placement and design of inlets to avoid capture of eggs and juveniles.

Analysis suggests that the proposed restoration program, if successful, could lead to a modest commercial fishery for alewives (and perhaps for bluebacked herring, smelt, and sturgeon) and an improvement in the existing striped bass fishery in the estuary. The most significant component, however, will be the sport fishery for Atlantic Salmon and American Shad. While it is difficult to determine the value of this fishery with precision, the study suggests that, taken together, the salmon and shad catch could have a value as recreation of from $1,500,000 to $3,000,000 per year in 1974 dollars. Most of this value would be realized within the region, though part of the expenditures related to the salmon fishery would be made elsewhere. The shad fishery appears to have substantial value as a source of food for residents of the Merrimack basin and adjacent areas, as well as for providing recreational opportunities.

2.4 Base Flow Determinations

Study of water quality parameters affecting the anadromous species as they relate to flow and discharge rates showed that for the most part, existing water quality is good enough to permit passage and reproduction of anadromous species and that flow and discharge was not a key factor in the maintenance of habitat except in the dam pools during low flow periods. Literature on the requirements of Atlantic Salmon indicate that temperature and existing water quality in the river during the spring months are adequate to permit passage of these species to the spawning grounds in the upper tributaries. Studies of the water chemistry requirements of the American Shad indicate that these parameters are also suitable for a spring and early summer breeding population of this species in the Lowell, Lawrence and Haverhill areas. The chief limiting parameter that seemed to relate to flow was found to be the concentration level of dissolved oxygen (DO). It was determined that Atlantic Salmon required a DO of 6 ppm while shad and other anadromous fish species could probably tolerate a DO of 5 ppm. At flows greater than 3,500 cfs the levels of DO were generally above 6 ppm. Accordingly, 3,500 cfs is considered as a critical flow volume to be maintained for purposes of anadromous fish requirements. More importantly, this river flow would insure that adequate flows are maintained over the fish ladders and that no stagnation or deoxygenation occurs in the pools behind the dams. It should also be noted that the requirement for 6 ppm during low flow periods is very close to the maximum measured existing DO levels in the river during summer months and that the saturation DO value for water at 86°F is 7.6 ppm.

Flow velocities of 1-2 ft/sec must be maintained during the months of March through October. Finally, water depths of from 3 to 30 feet are required for shad reproduction in those portions of the river used for spawning.

Requirements for municipal water supply currently represent an insignificant drain on the river and future withdrawals within Massachusetts are expected to grow to only about 110 cfs by 2020. Withdrawals for power generation (returned to the river below the dams) at Lowell and Lawrence represent more significant requirements which could be impacted by a large scale diversion program. These requirements, however, were considered in the establishment of necessary flows and will not be compromised by the proposed diversion program.

2.5 Diversion Studies

The final task of the study was to combine the data and correlate the more significant impact analyses in order to establish criteria for necessary flows and the limits of diversion in order to assess whether future water supply requirements would add significantly to the stresses imposed by existing impediments to the restoration of anadromous fish runs. Potential diversion rates examined were: 100 cfs, 200 cfs, 500 cfs, 800 cfs, 1,100 cfs, 1,500 cfs and 2,000 cfs. Control flows, which are flows that must be maintained in the presence of a diversion program, were established on the basis of flow levels required to insure the restoration of an anadromous fishery for salmon and shad, taking into consideration some existing limiting constraints of the natural operating system. These were tabulated on a month by month basis and compared to average flows for these same months. Control flows ranged from a low of 2,000 cfs to a high of 6,000 cfs. The impacts of the selected diversion rates were then examined on a month by month basis for conditions of average flow, average minimum flow, an average maximum flow. None of the diversions has any impact on control flows during the months of February, March, April, and May. Any diversion during August and September would violate control flow requirements, but control flows for these months are rather superficial since the average natural flows fall well below the required minima for operation of fish ladders and for prevention of deoxygenated waters in the dam pools. For the other months the relationship between withdrawal rates and control flows varied with the rate being examined and with the flow (average, minimum, or maximum). During high flow years diversions up to 2,000 cfs could be accomplished during any month of the year without affecting control flows. For low flow years this withdrawal rate could be sustained only during February, March, and April. No diversion at all would be permissible from June through November. Diversion rates lying between 1,100 and 1,500 cfs could occur during January, May, and December.

The potential volume of water that might be withdrawn by a diversion program is substantial. Assuming maximum withdrawals permitted by flow control considerations and diversion rates in the range of 100 to 2,000 cfs, in an average year 0.9 million acre-feet could be removed from the river without affecting the fishery. Under low flow conditions this would be cut to about 0.6 million acre-feet. Under high flow conditions it could increase to just over 1.4 million acre-feet.

The location and design of the diversion water intake could impact on the fishery. Surveys of the distribution of substrates in the river conducted by the Massachusetts Fish and Game Department (Oatis and Bridges, 1969) and the Federal Water Pollution Control Administration (Oldaker, 1966) show that the predominant substrates from Tyngsboro Island to the river mouth are sludge and silt with some sand. The prime substrates for shad spawning appear to lie just below the Massachusetts state line and in New Hampshire. The preferred general location appears to be in Reach 1, above the Pawtucket Dam at Lowell. Since the upper portions of this reach represent shad spawning habitat, a location close to the dam would be preferred to avoid excessive capture of floating eggs, fry, and small fish. Placement of the intake near the top of the water column would further reduce losses, since the eggs and small fish tend to concentrate near the bottom. Inlet design that would limit intake velocity at the mouth to 0.5 feet per second or less, in conjunction with protective screens and baffles, would minimize attraction of down-migrating young fish and spent adults by the withdrawal plane. Finally, maintenance of spawning habitat requires a water depth of no less than 3 feet. This would not present a problem in any part of the river under study with the withdrawal rates examined.

2.6 Conclusions

This study has demonstrated that substantial diversions of water from the Merrimack River are possible without compromising either proposed anadromous fish restoration programs or other river-related resources. This can be accomplished by a diversion policy which does not allow river flows to fall below control flows especially during the peak spring migration months. From January until June and during November and December, average flows in the Merrimack are more than sufficient for the requirements of anadromous fisheries. Natural flows during late summer and early fall months (July through October), on the other hand, are often below the required flow levels. Additionally, temperature levels during these months are often at or above the 22-25°C requirements for shad and Atlantic Salmon. Thus, late summer migrations are not likely in the Merrimack. This, however, was most probably the case historically as well. The indication is that a spring migrating race of salmon inhabited the Merrimack. The fact that there is only one spring race may well increase the number of years required to establish the fishery, but should not prevent success in the program.

3.0 THE RIVER

3.1 Physical Characteristics

3.1.1 Plan and Profile

The Merrimack River Diversion Study Area consists of the main-stem of the Merrimack River from Manchester, New Hampshire to the mouth at Newburyport, Massachusetts. (See Figure 1) Within this stretch of the river, the overall gradient is 1.2 feet/mile. Water flowing in the 3 reaches of the Merrimack studied is regulated at present by two dams, the Pawtucket Dam (elevation 87.2 feet above mean sea level) in Lowell and the Essex Company Dam (elevation 39.2 feet above mean sea level) in Lawrence. The two dams and their associated river subdivisions are the basis for defining the three particular reaches of study shown in Figure 3. Reach 1 extends a total distance of 22.5 miles from the Pawtucket Dam to the end of the dam pool at Manchester, New Hampshire. The length of the dam pool is an arbitrary distance which corresponds to the upstream projection of the dam crest elevation until it intersects the river bed profile. Reach 2 extends from the Pawtucket Dam to the Essex Company Dam, a total distance of 7.5 miles. Reach 3 consists of the 29 miles of river from below the Essex Dam to the mouth of the Merrimack in Newburyport. (See Figure 2)

Within the three reaches of the Merrimack Study Area there are four major tributaries with drainage areas larger than 50 square miles. (see Figure 3) These tributaries are: the Souhegan River in Reach 1 with a drainage area of 219 mi^2, the Nashua River in Reach 1 with a drainage area of 530 mi^2, the Beaver Brook in Reach 2 with a drainage area of 91 mi^2, and the Concord River in Reach 2 with a drainage area of 406 mi^2. (Corps of Engineers, 1972)

3.1.2 Cross - Sections

Flow within the three reaches of the Merrimack River study area is generally contained in constricted U-shaped stream channels. Seven cross-sections (labeled A-G) are included to illustrate the types of cross-sectional profiles present in the study area. The locations of the cross-sections are

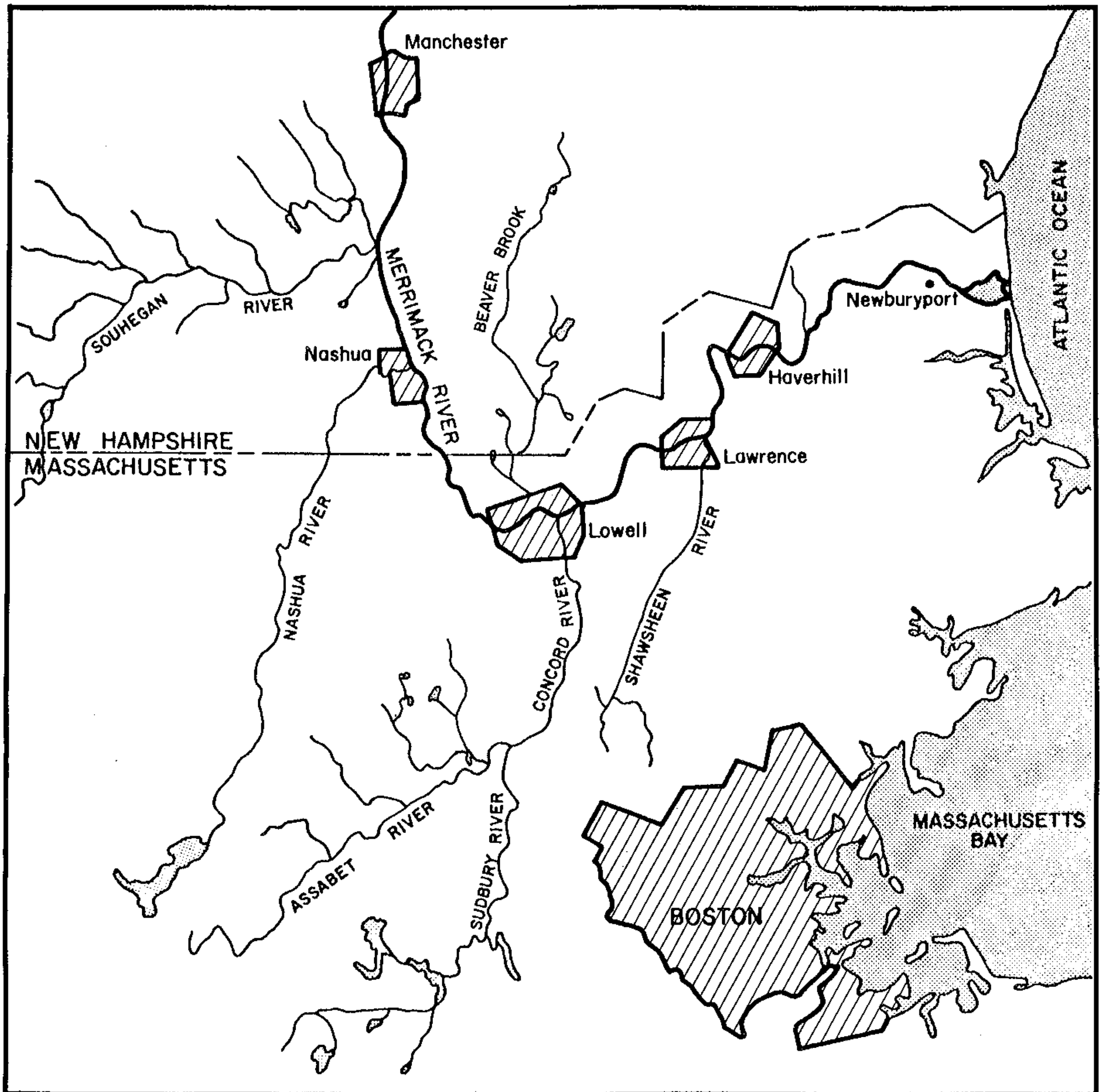


Figure 1

Location of Study Area

Merrimack River Diversion Study

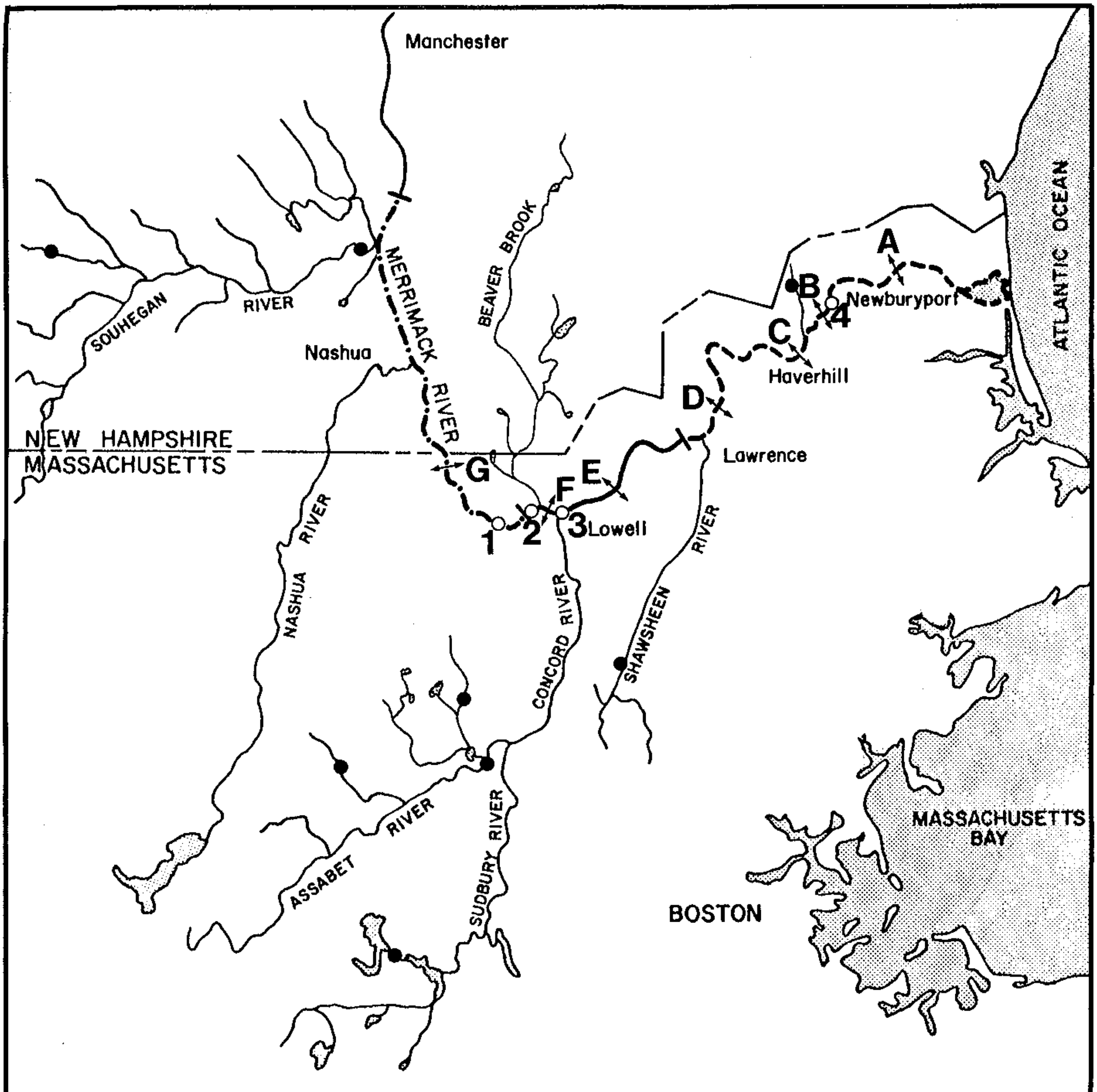


Figure 2

Plan Map

● U.S.G.S. gaging station

○ U.S.G.S. water quality station

\ Merrimack dams

Locations of cross sections and stage discharge measurements

Reaches:
1
2
3

Merrimack River Diversion Study

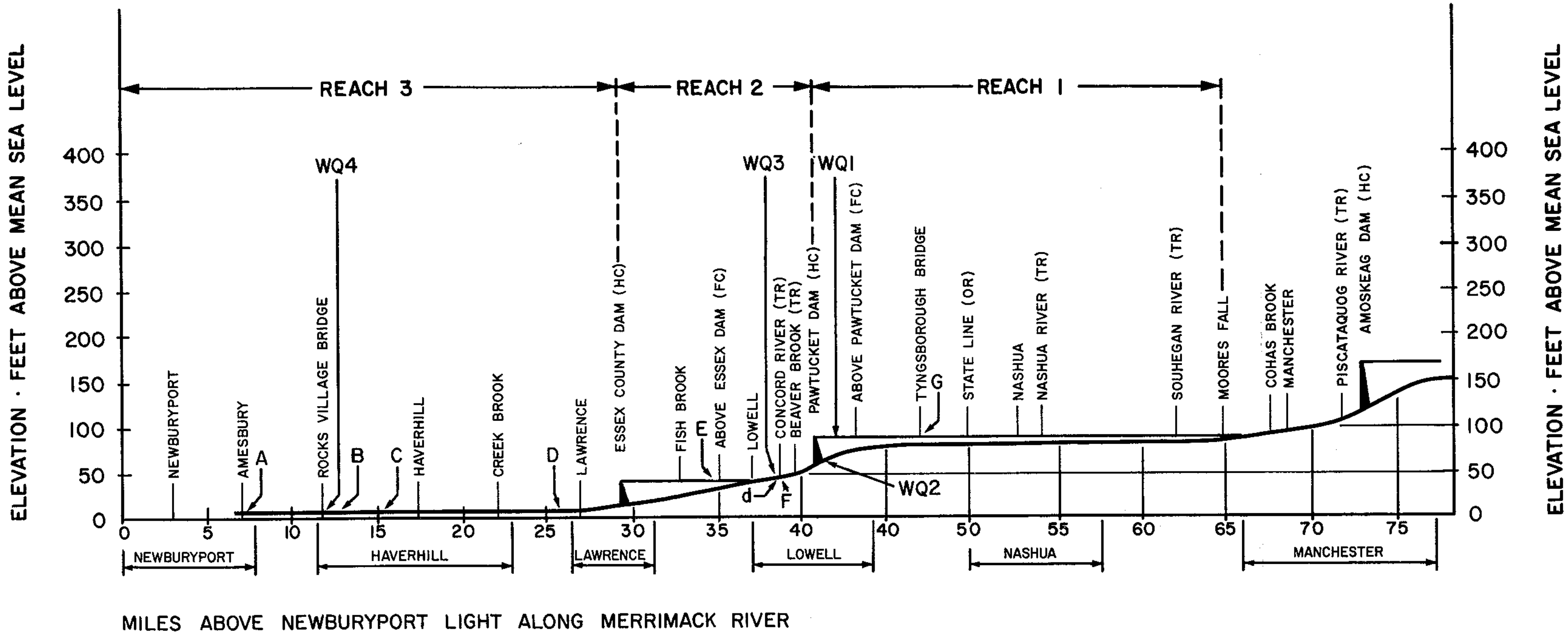


Figure 3

Longitudinal Profile of Study Area

(TR) Major Tributaries (Conjunctions)

(HC) Hydraulic Control Points (Dams)

(FC) Flow Changing Points

A Cross-section and Stage/Discharge Rating Location

d U.S.G.S. Gaging Station

WQ-I U.S.G.S. Water Quality Sampling Station

Dams Showing Normal Water Line

Merrimack River Diversion Study

shown in Figures 2 and 3. Cross-sections labeled "D" and "G" (Figures 4 and 5) are typical examples of the Merrimack River channel configuration in Reaches 1 and 3. Water is contained in a relatively narrow confined channel throughout much of the year. Only during flooding periods, as shown by flood water levels, does the Merrimack leave its narrow channel. The remaining cross-sections (A,B,C,E,F) are presented in Appendix A.

3.1.3 Stage - Discharge

Presented with each of the cross-sections A-G are stage-discharge rating curves. The relation shown by each curve is a result of plotting numerous simultaneous water level elevations (stage) and stream discharge measurements. With each curve it is possible to determine the water level corresponding to any discharge measurement (or vice versa) at the given cross-section locations.

Such curves were not available for the Pawtucket or Essex Dams. At these locations, withdrawals to the canal systems control stage. Design studies for fishways at these locations, however, indicated that flow over the dams will generally be observed if river discharge exceeds 3,500 cubic feet per second. (Daley, 1975)

An examination of the cross-sections and stage-discharge relationships indicates that, because of ponding behind the dams and the regular, U-shaped nature of the channel, flows may approach zero without reducing water depths at mid-stream to less than ten to fourteen feet. Shallow water conditions can be expected during low flows at some areas in the River (near Kimball Island in Haverhill, for example) but the only locations where low flow will present grave physical problems to fish are at the two dams. In these locations, flows below 3,500 cfs will be entirely diverted, resulting in no flow over the rapids beneath the dams. These problems have been considered in the preliminary design of fishways for these dams (Daley, 1975) and the flows needed are included in the base flow requirements established for the restoration of anadromous fish. These, then, are the critical cross-sections of the Merrimack River especially insofar as a potential anadromous fishery is concerned.

3.2 Hydrology

Discharge measurements for the three reaches of the Merrimack study area were compiled from existing U. S. Geological Survey gaging records. The Survey operates only one continuously recording discharge gage on the Merrimack River within the

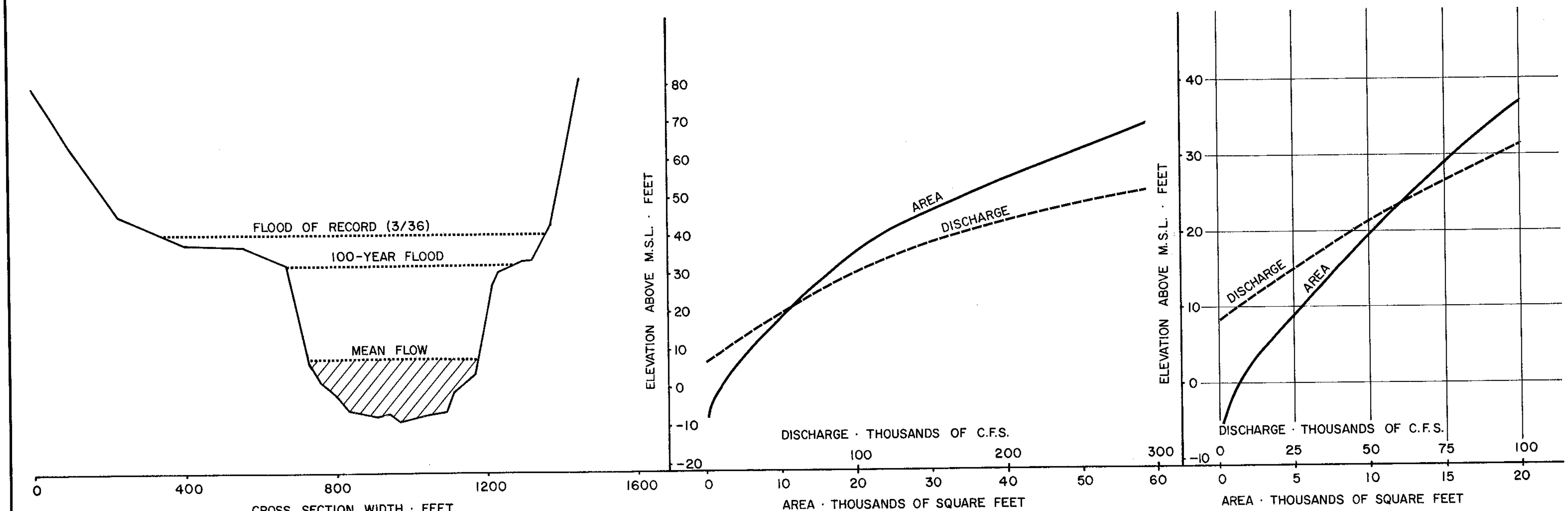


Figure 4

Cross Section and Stage Discharge Relationship at Location D (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

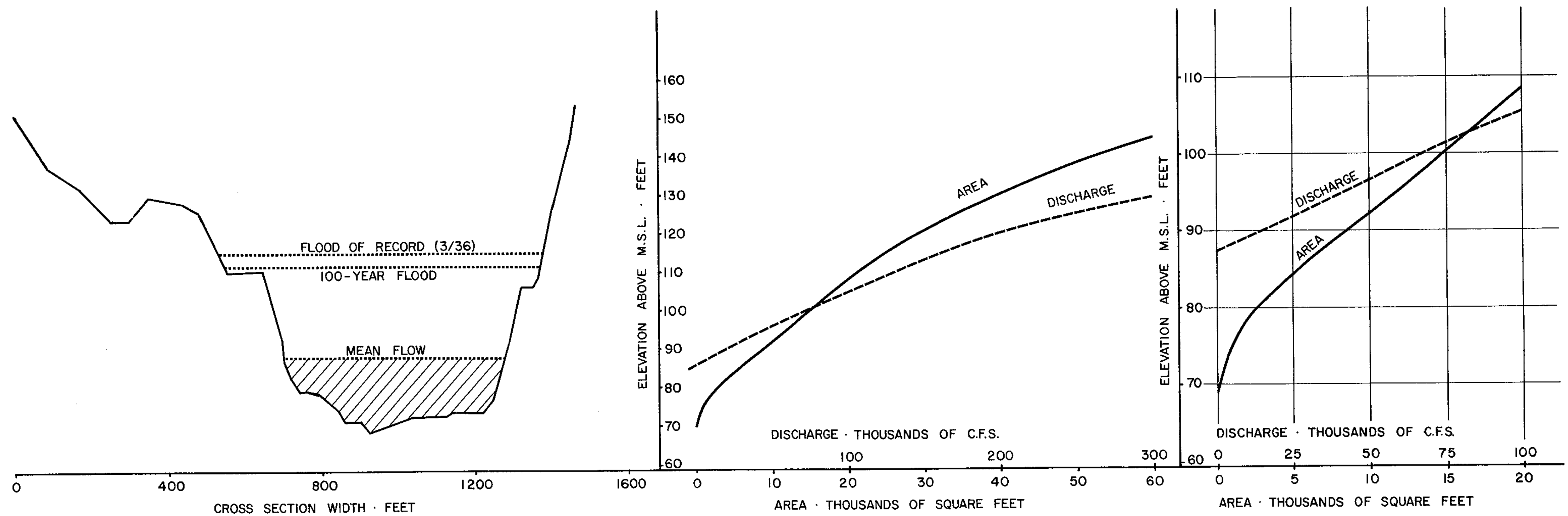


Figure 5

Cross Section and Stage Discharge Relationship at Location G (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

limits of the study reaches. This gage is located 1100 feet downstream from the confluence of the Concord and Merrimack Rivers in Lowell and about two miles below the Pawtucket Dam. The discharge obtained at this gaging station is a good measure of the water in the Merrimack from over 93% of the total 5,010 square mile drainage basin.

The remaining 38 mile length of the Merrimack below the Lowell gaging station receives runoff from only 7% (367 square miles) of the total basin drainage area. Consequently the added discharge in the Merrimack beyond the Lowell gage is not thought to be of significance. Previous studies of effects of Merrimack diversion on estuarine conditions (Normandeau, 1971) relied solely upon discharge base data from the Lowell gaging station for all discharge-related calculations.

Obtaining more accurate approximations for discharge below the Lowell gaging station is difficult because of the lack of appropriate mainstem gaging stations. Below Lowell, the U.S.G.S maintains only two gaging stations in the remaining 7% of the Merrimack drainage basin. The stations are located near the headwaters of the Shawsheen River and the East Meadow River. (See Figure 2)

Discharges obtained at these stations were examined to evaluate possible significance. Based upon the average yearly discharge flowing through these gaging stations, it was determined that the discharge measured at the Shawsheen amounted to a 0.6% addition in Merrimack volume while there was less than 0.1% addition at the East Meadow River. These percentages are based upon U.S.G.S. average yearly flow figures at the Lowell, Shawsheen, and East Meadow gaging stations.

After evaluating the data from existing U.S.G.S. gaging stations in the lower Merrimack basin, it was felt that valid discharges for each reach could be obtained by manipulating discharge data from the Lowell, Concord River, and Shawsheen River gaging stations. Data from the East Meadow station were not used because of the negligible addition to the average Merrimack River volume there. The discharge at Reach 1 was compiled by subtracting the discharge measured at the Concord station (near the mouth of the Concord River) from the discharge measured at the Lowell Station on the Merrimack. The discharge figures for Reach 1 unfortunately included the discharge from Beaver Brook in Reach 2. Because there was no gaging station on Beaver Brook, it was impossible to obtain useful figures needed for the computation. The discharge at Reach 2 was simply the discharge measured at the Lowell gaging station. The discharge at Reach 3 was the sum of the discharge measured at the Lowell gage plus the discharge measured at the Shawsheen River.

In all cases, the U.S.G.S. discharge data from each station were expressed in terms of the daily mean. The daily means for a given month were then averaged and tabulated into weekly means. The weekly means are based upon 3 consecutive 8-day weeks followed by a 7 day week. The discharge data for 1968 through 1973 were chosen as a base for the study. Discharges during this 6-year period were examined for correlation with various water quality parameters. Water quality/discharge correlations for the last 6 years of record should give a reasonable indication of current industrial, domestic, and general background conditions in the study reaches of the Merrimack River.

For the information requirements of this study it was felt that daily fluctuations in flow and water quality parameters were not as important in portraying river conditions as were weekly trends observed over the long term. Moreover, due to the time lag in the responses of aquatic organisms to changes in water quality parameters and to the mobility of anadromous species, expressing the daily values of these parameters would not be as meaningful as the averaged weekly means. Since the amount of additional information that would be contributed by illustrating the data on a daily basis would be minimal, it was decided that the capacity of the river to support aquatic life under current and projected water quality conditions could be adequately inferred from the weekly averages and week to week trends in flow rates and water quality parameters.

The mean weekly discharges during 1968-1973 of each of the three study reaches are compiled in Table B.1 of Appendix B. The data are presented in terms of hydrologic water year which starts in October and continues through 12 months to the following September. Hydrographs of mean weekly discharge versus time were also constructed for each reach during each of the years from 1968-1973. All hydrographs (Figures B.1-1 to B.3-3) appear in Appendix B. Comparison of the discharge data and plotted hydrographs indicates that little variation in discharge occurs between Reaches 1, 2, and 3. In Figure

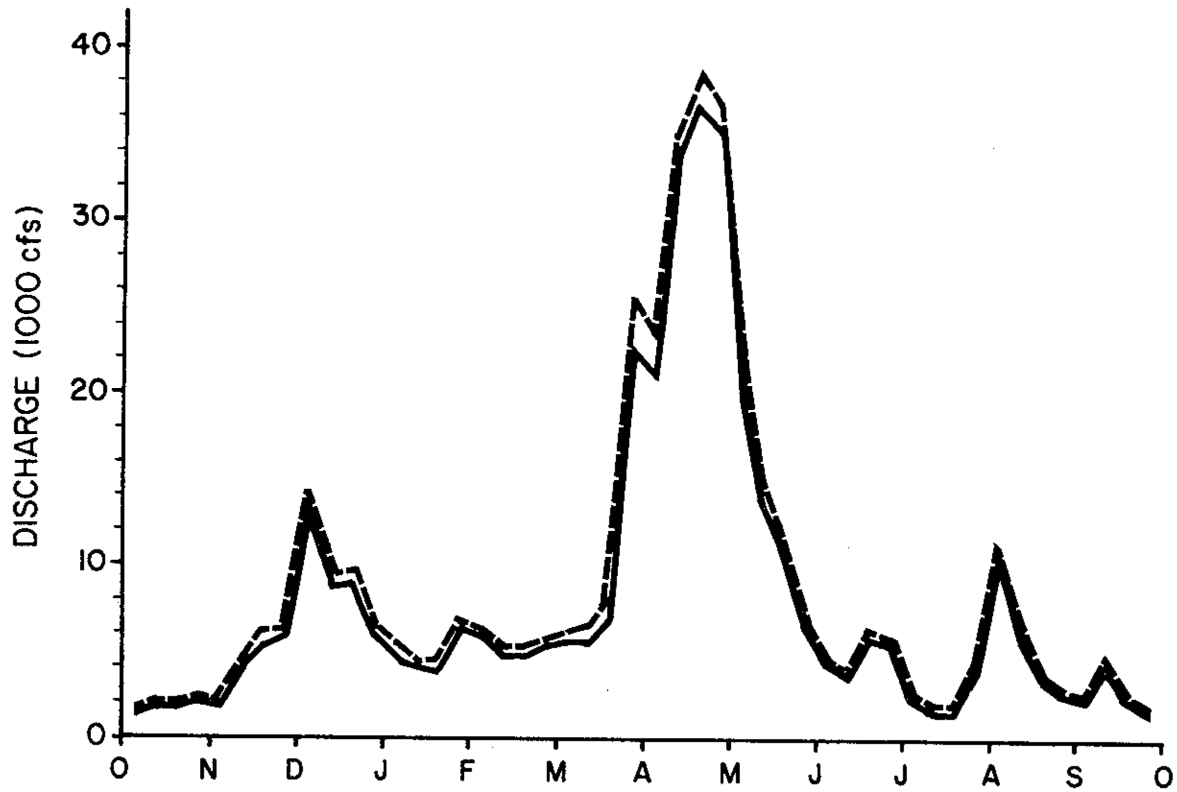


Figure 6

Comparison of 1969 Discharges Reach 1 and Reach 3

Merrimack River Diversion Study

6 for example, the 1969 discharges are moderate. The greatest differences occur primarily during peak flows from late March to the end of May. A statistical comparison of mean calculated discharges for Reach 3 versus Reach 1 indicates that the difference in water volume averages less than 6%. Data on average monthly and yearly discharges during 1968-1973 appear in Table 3.0.

Discharge data beyond the last 6 years was also used to evaluate flow conditions in the Merrimack. The U.S.G.S. has discharge data at the Lowell gaging station dating back to 1927.

Unfortunately, discharge records at the Concord River gage date back only to 1936 and at the Shawsheen only to 1963. Therefore, for further discharge considerations such as prediction of peak flood flows, drought flows, and mean flows discharge data from 1927-1973 at the Lowell gage were used. These data (from Normandeau, 1971) appear as mean weekly discharge in Table B.2 of Appendix B.

These data were used to construct three sets of flow-duration relationships. These were prepared for each month by interval counting the highest weekly flow, the lowest weekly flow, and all weekly flows. The high flow data are an estimate of the return period (or relative frequency) of the seven-day high flow. The low flow data are those for the seven-day low flow. The average data represent the weekly average flow in the river. Table 3.1 is a summary of the flow-duration relationships determined from weekly average flow data.

3.3 Water Quality

3.3.1 Method

Recent data on water quality measurements in the three reaches of the Merrimack River under study were obtained from the U.S. Geological Survey. Data from the Survey were relied upon exclusively because: (1) Survey data have an excellent reputation for accuracy and reproducibility; (2) water quality measurements were available at all three study reaches; (3) data on a large number of parameters were available for a long period of time; and (4) the water quality data could be reasonable correlated with U.S.G.S. discharge data because of the close proximity of gaging stations and water quality sampling stations. As was the case with the discharge data, water quality data were compiled for the 6 year period from 1968-1973. Again, it was felt that data from this time span would be indicative of recent natural and human-related conditions in the Merrimack.

TABLE 3.0

Monthly Means and Standard Deviations in Discharge, Reach 1, Merrimack River from 1968-1973. Base Data from U.S.G.S.

	1968		1969		1970		1971		1972		1973	
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
Oct.	2741	374.0	1868	160.2	1879	241.2	2898	1158	2027	501.4	2741	972.1
Nov.	3614	1141	4269	1774	10440	4818	3992	1141	1632	958.8	9115	4638
Dec.	6196	1698	9057	3186	10910	5574	4540	655.3	4285	746.4	10890	2514
Jan.	4022	289.8	4796	892.6	8286	3148	3807	314.8	4635	220.6	12150	4663
Feb.	4231	1262	5146	441.4	15910	7605	4748	1097	5344	944.2	13950	9098
Mar.	15830	14490	10050	8130	9259	4620	8308	2046	13300	6875	18880	8420
Apr.	13370	5502	31440	7131	21980	882.0	20440	3012	21390	6838	20600	7108
May	9779	3415	12970	6026	10980	3746	15350	6180	17510	6630	15660	2463
Jun.	11110	1071	4754	1159	3339	1280	3123	1385	8909	3069	7774	2327
Jul.	5301	4275	2459	923.9	2014	552.9	1479	327.7	6347	880.4	13520	11460
Aug.	1736	330.6	5534	3584	1455	248.3	1981	648.5	2725	719.4	3678	2271
Sept.	1586	359.2	2480	1039	1576	244.5	1952	313.2	1963	499.3	1958	289.4
Annual	6625	6231	7902	8579	8169	7038	6051	6038	7585	6993	10910	7784

TABLE 3.0 (continued)

Monthly Means and Standard Deviations in Discharge, Reach 2, Merrimack River from 1968-1973. Base Data from U.S.G.S.

	1968		1969		1970		1971		1972		1973	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Oct.	2938	393.3	1940	173.2	2065	225.3	3053	1257	2153	546.3	3033	1109
Nov.	3913	1286	4653	1945	11210	5094	4327	1198	2293	132.0	1010	5036
Dec.	6778	1781	9725	3118	12060	5836	4954	634.8	4830	741.4	12390	2686
Jan.	4513	266.3	5310	1036	9323	3601	4177	343.9	5170	257.0	13320	4757
Feb.	4820	1490	5618	510.4	17710	8048	5350	1368	5980	1007	15150	9473
Mar.	17810	16150	11220	9089	10300	4854	9859	2273	15560	7562	19900	8546
Apr.	14450	5829	33290	6706	23600	1300	15930	9185	22860	6706	21980	7372
May	10350	3469	15980	5443	11700	3871	16270	6155	18880	6759	16590	2470
Jun.	11850	1171	4910	1129	3775	1437	3446	1556	10190	3090	8342	2408
Jul.	5883	4636	2548	927.7	2203	637.4	1571	337.6	6900	1029	14170	11780
Aug.	1840	372.1	5685	3688	1570	267.7	2094	683.3	2935	784.1	4025	2408
Sept.	1648	373.8	2645	1101	1705	273.3	2067	347.2	2165	500.8	2164	320.1
Annual	7232	6860	8437	9072	8935	7595	6561	6376	8326	7555	11760	8144

TABLE 3.0 (continued)

Monthly Means and Standard Deviations in Discharge, Reach 3, Merrimack River from 1968-1973. Base Data from U.S.G.S.

	1968		1969		1970		1971		1972		1973	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
Oct.	2957	396.3	1946	172.8	2082	225.0	3073	1270	2166	552.6	3033	1109
Nov.	3944	1308	4706	1966	11320	5161	4365	1200	2322	139.0	1010	5036
Dec.	6834	1789	9791	3134	12220	5962	4992	637.8	4871	733.3	12390	2686
Jan.	4563	261.0	5361	1053	9395	3634	4205	348.8	5216	259.8	13320	4757
Feb.	4886	1539	5659	523.5	17860	8100	5420	1405	6033	1002	15150	9473
Mar.	17980	16280	11380	9252	10390	4880	10000	2299	15790	7573	19900	8546
Apr.	14520	5836	33420	6681	23720	1362	21630	3084	22960	6718	21980	7372
May	10400	3478	13730	6389	11770	3898	16350	6170	18980	6783	16590	2470
Jun.	11930	1186	4927	1128	3315	2200	3479	1568	10330	3132	8342	2408
Jul.	5923	4663	2559	928.3	2220	647.8	1583	336.4	6951	1044	14170	11780
Aug.	1854	380.8	5701	3703	1584	267.8	2107	692.7	2951	790.3	4025	2408
Sept.	1656	379.1	2665	1113	1718	276.4	2074	348.3	2096	635.6	2164	320.1
Annual	7288	6910	8487	9114	9008	7652	6607	6402	8389	7605	11760	8144

TABLE 3.1

FLOW DURATION SUMMARY
Merrimack River at Lowell, Massachusetts

	MAX.			MIN.			AVG.		
	10%	50%	90%	10%	50%	90%	10%	50%	90%
JAN.	17000	9000	3800	6800	3400	2200	11800	5000	3200
FEB.	17600	8600	4400	7200	4200	2400	12400	6200	4000
MARCH	29000	17000	10000	11200	7000	3800	20200	10400	5200
APRIL	37000	25000	15400	20000	11800	6400	32000	17000	9400
MAY	22800	14400	7600	11600	6600	3400	18800	9600	4800
JUNE	16400	8000	3400	7000	3000	1600	11800	5000	2600
JULY	9200	3600	2000	3400	1800	1000	6600	3000	1600
AUG.	7200	2800	2000	2800	1200	1000	5000	2400	1400
SEPT.	7800	3000	2000	2600	1200	800	5000	2200	1400
OCT.	11200	4600	2200	3600	1600	1200	7200	3000	1400
NOV.	17800	7200	4000	7600	3000	1200	12600	4800	2800
DEC.	18600	7400	4000	7000	3200	2000	14000	5400	3400

Note: The years 1968-1973, used for water quality baselines, were not particularly dry years. There were, however, occurrences of flows near or below the seven-day, ten-year low flow (90% minimum) for many months. For comparison, the lowest seven-day flow recorded for each month during 1968-1973 are:

Jan.	4280	July	1250
Feb.	3390	Aug.	1300
March	3480	Sept.	1410
April	9390	Oct.	1400
May	6570	Nov.	2010
June	2150	Dec.	3570

Four U.S.G.S. water quality monitoring stations located in the study area were relied upon for all water quality base data. Their locations are shown in Figures 2 and 3. Stations 1 and 2 lie in Reach 1. Station 1 is located on the north bank of the Merrimack at the intake of the Lowell water treatment plant, 2.7 miles upstream from the Pawtucket Dam. Station 2 is located in the gatehouse of the Pawtucket Dam, 1.8 miles upstream from the Concord River. Station 3 is in Reach 2 at the Hunts Falls Bridge, 300 feet upstream from the Lowell discharge gaging station. Station 4, which lies in Reach 3, is located at the Bridge Street Bridge, 0.9 mile northwest of West Newbury.

The water quality parameters measured at the four monitoring stations are listed in Table 3.2. A total of 38 major constitutents, 26 minor constituents (metals), and 22 pesticides and herbicides were included in the U.S.G.S. water quality analysis. Not all parameters were measured at each of the four stations. Also, not all of the stations were in operation during the six years from 1968-1973.

> Station 1 was in operation from 1970-1973. During that period, monthly measurements of an average of 12 parameters were collected. During 1973, 24 parameters were analyzed on a monthly basis and continuous daily monitoring of water temperature and specific conductance was begun.
>
> At Station 2, in operation from 1968-1972, continuous monitoring of pH, temperature, dissolved oxygen (DO), and specific conductance took place during 1968 and 1969. During 1970 only temperature and specific conductance were continuously monitored. A small number of parameters were measured on a non-regular quarterly basis.
>
> At Station 3, in operation from 1968-1972, sediment concentration was continuously monitored. Also, numerous parameters were analysed four to six times during each year.
>
> Finally, at Station 4, operating from 1969-1973, pH, temperature, dissolved oxygen, and specific conductance were continuously monitored. In 1969, sixteen additional parameters were analyzed during the year.

Trace constituents and pesticide/herbicide levels were measured only at Station 1. Data from all four Stations are to be found in the U.S.G.S. Open File Reports, 1968,

TABLE 3.2

Water Quality Parameters Considered in Merrimack River Diversion Study. Base Data from U.S.G.S.

Major Constituents

Sediment discharge	Non-carbonate hardness
Sediment concentration	Alkalinity
pH	Acidity
Temperature	Sulfate
Dissolved oxygen	Chloride
Dissolved solids	Phosphate
Silica	Total phosphorus
Calcium	Specific conductance
Magnesium	Turbidity
Sodium	Fecal coliform
Potassium	Carbon dioxide
Nitrogen - total	Biochemical oxygen demand
Nitrogen - ammonia	Chemical oxygen demand
Nitrogen - Kjeldahl	Oil and Grease
Nitrogen - nitrate	Phenols
Nitrogen - nitrite	Color
Bicarbonate	Chlorophyll
Carbonate	Methylene blue active substances
Hardness	

Minor Constituents (metals)

Antimony	Molybdenite
Arsenic	Nickel
Barium	Silver
Berylium	Strontium
Bismuth	Vanadium
Boron	Tin
Cadmium	Zinc
Chromium	Aluminum
Cobalt	Gallium
Copper	Germanium
Iron	Lithium
Lead	Titanium
Manganese	Zirconium

Pesticides and Herbicides

Aldrin	Heptachlor epoxide
Lindane	PCB
Chlorodane	Malathion
DDD	Parathion
DDE	Diazinon
DDT	Methyl parathion
Dieldrin	2, 4-D
Endrin	2, 4, 5-T
Ethion	Silvex
Toxaphene	Trithion
Heptachlor	Methyl trithion

1969, 1970, 1971, 1972, and 1973. Mean monthly water quality tabulations are found in Appendix C.

3.3.2 Water Quality Analysis

A comparison of the mean monthly water quality values listed in Appendix C suggests that, in general, water quality does not vary greatly from reach to reach. There is a major difference in the nature of the reaches however. Reach 3 is estuarine, whereas Reaches 1 and 2 are completely fresh-water in nature. This difference is illustrated graphically in Figures 7 and 8. These figures present bar graphs of mean monthly values of temperature, DO, and specific conductance at Reach 1 (Station 2) and at Reach 3 (Station 4). The three water quality parameters are similar in the two reaches. However, dissolved oxygen is lower in Reach 3 during the summer and fall months. Also specific conductance, a measure of overall dissolved constitutents, is slightly higher during most of the year in Reach 3. These differences in DO and specific conductance point out the small but definite chemical difference in the natures of the two Reaches.

In order to determine if large-scale seasonal, discharge-related, or other parameter-related variations occur, a large number of combined and single water quality parameters were plotted against individual yearly Reach hydrographs. In all cases, only parameters for which there were four or more measurements during a given year were plotted. Table 3.3 is a tabulation of the water quality parameters plotted for each reach. Yearly water quality parameters measured in Station 1 and 2 were plotted against the corresponding yearly hydrograph of Reach 1. Station 3 data were plotted against Reach 2 hydrographs and Station 4 data were plotted against Reach 3 hydrographs. A total of 47 plots for Reach 1, 33 plots for Reach 2, and 15 plots for Reach 3 were constructed in order to determine water quality relationships. These plots appear in Appendix C.

As noted earlier (Figures 7 and 8), most water quality parameters do not vary significantly from reach to reach. Where identical parameters are plotted against individual hydrographs, only minor differences appear evident. The parameters showing similarity include the plots of temperature, specific conductance, the several forms of nitrogen, and pH. Dissolved oxygen, however, is often somewhat lower in Reach 3 than elsewhere, especially during the summer. However, the appearance of plot similarity is influenced by the number and frequency of data points. Plots based upon mean weekly data points are considerably different from

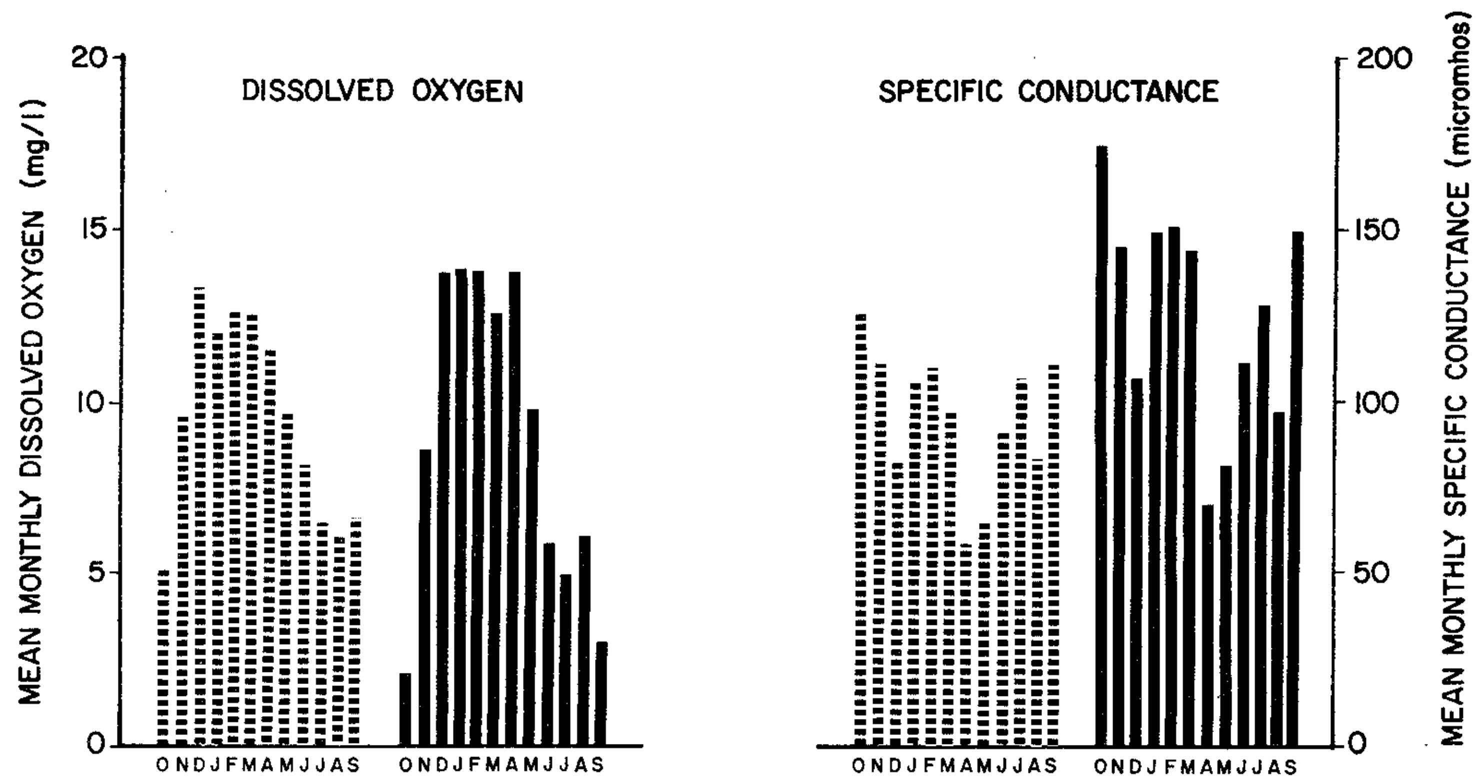
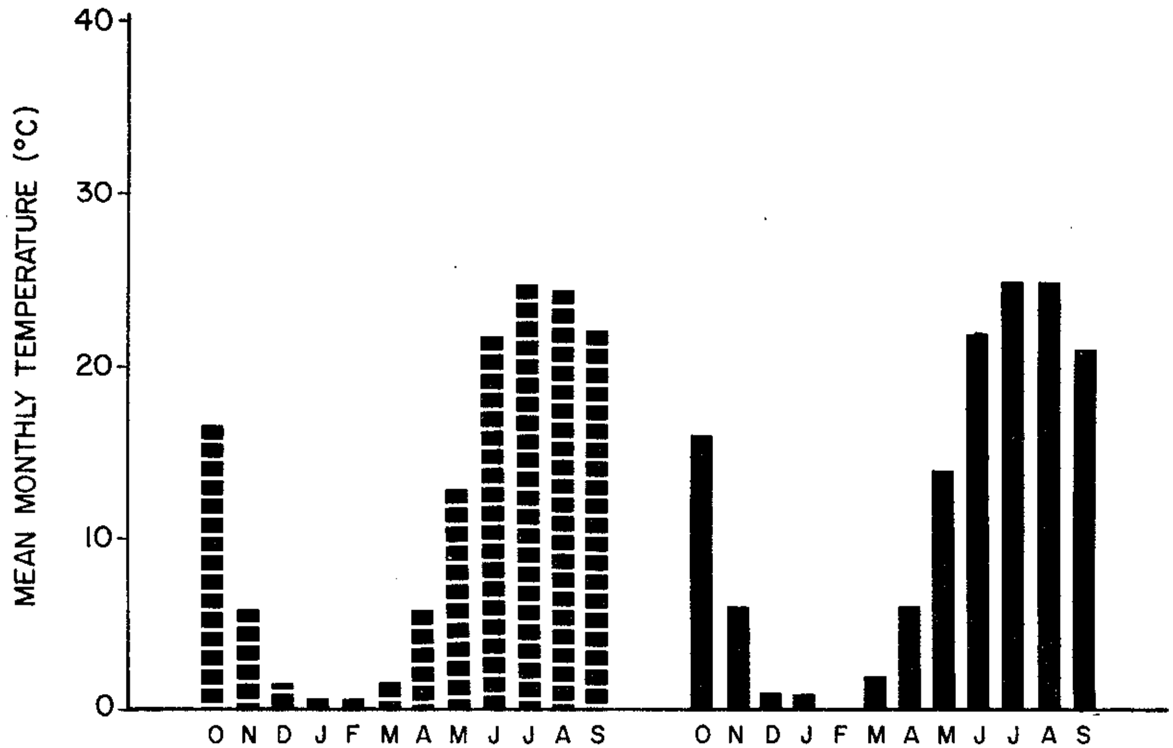


Figure 7

Comparison of 1969 Mean Monthly Dissolved Oxygen and Specific Conductance Reach 1 and Reach 3

Merrimack River Diversion Study



Reach 1
Reach 3

Figure 8

Comparison of 1969 Mean Monthly Water Temperatures Reach 1 and Reach 3

Merrimack River Diversion Study

TABLE 3.3

Individual and Combined Water Quality Parameters Plotted Against Yearly Hydrographs of 1968-1973, Reaches 1, 2, 3, Merrimack River Diversion Study. Base Data from U.S.G.S.

Reach	Parameter
1	Temperature - Dissolved Oxygen (DO)
	pH
	Fecal Coliform
	Phosphorus - Methylene Blue Active Substances
	Chemical Oxygen Demand (COD)
	Turbidity
	Chlorophyll
	Nitrogen (Nitrate - Kjeldahl Nitrogen)
	Specific Conductance
2	Calcium - Magnesium - Hardness - Bicarbonate
	Nitrogen (Nitrate - Nitrite - N Ammonia)
	Sulfate - Chloride
	Sodium - Potassium - Silica
	Iron - Manganese
	Sediment Concentration - Sediment Discharge
	Specific Conductance - Dissolved Solids
3	Temperature - Dissolved Oxygen
	pH
	Specific Conductance

plots based upon mean monthly or bi-monthly data points. The most useful plots are those constructed from the greatest number of data points. An apparent drawback to the water quality plots is the lack of parameter comparison from reach to reach. Only five parameters are duplicated in plots from reach to reach. However, based upon previously established similarity in discharge, specific conductance, pH, and temperature, it is assumed that other water quality parameter (such as sodium, iron, phosphate, etc.) relations established for any one of the reaches will be largely valid for the remaining two.

In terms of observed water quality relationships, all parameters plotted against yearly hydrographs fall into three main categories. The first category includes all parameters that were discharge-controlled. These parameters fluctuated quantitatively in response to dilution during high flows and concentration during low flows. The second category includes parameters which are not dependent upon discharge but are dependent upon seasonal climatic changes. The final category includes parameters which are neither discharge nor climate-controlled and parameters for which insufficient data are available to make valid judgements.

3.3.3 Discharge-related Parameters

A general comparison of yearly discharge curves and corresponding water quality curves indicates that, for some parameters, water quality and Merrimack River discharge are related. An obvious example of such a relationship is that of sediment concentration and sediment discharge versus Merrimack discharge in Reach 2. (Appendix C) High and low points in the discharge curves correspond to nearly identical high and low points in the concentration curves. Unfortunately, where data points are not abundant, this kind of relationship is not always clear. Consequently other parameters that were likely to be discharge-related were analyzed for flow dependence.

The model used to test water quality-discharge dependence was that of Hem (1970). According to Hem, the simplest model for a particular water quality constituent in a reach of a river is one which assumes that a constant total load of that constituent is entering upstream. Also, it is assumed that the observed concentration of the constituent at the sampling point varies with runoff dilution.

If other factors are considered to have minimal effect, then this condition can be evaluated from a simplified form of the constituent balance equation (Hem, 1970):

$$C_1Q_1+C_2Q_2 = (Q_1+ Q_2)\ C_3 = C_3D \tag{1}$$

Q_1 = flow volume before dilution
C_1 = constituent concentration before dilution
Q_2 = volume of dilution water
C_2 = constituent concentration in diluting water
C_3 = final observed concentration
D = total flow

The 3 terms in the above equation represent load of an observed water quality element and an inflow-outflow balance is assumed. If C_1Q_1 is constant (as assumed) and if C_2 is 0, then

$$\frac{C_1Q_1}{D} = C_3 \tag{2}$$

When C_1Q_1 is constant, it can be represented as W_1, the total original load of the constituent. If this equation is expressed in logarithmic form,

$$\log C_3 = \log W_1 - \log D \tag{3}$$

then the equation has the form of a straight line with slope -1.0. Therefore according to Hem, the degree to which a particular set of concentration and stream discharge data fits the dilution model can be tested by plotting concentration and discharge on log - log paper. Most natural systems can display a simple dilution mechanism only over a limited range of concentration. Inherent complexities tend to make the solute balance equation much more complicated. If, for example, some quantity of the water quality constituent being considered is actually present in runoff, the value of C_2 is not 0 , and the final equation has the form

$$\frac{W_1 + C_2Q_2}{D} = C_3 \tag{4}$$

Expressed in logarithmic terms as:

$$\text{Log } C_3 = \text{Log } (W_1 + C_2Q_2) - \log D \tag{5}$$

this equation will give a curved line. It is in fact unlikely that $C_2 Q_2$ will ever be constant and will probably also vary in response to discharge.

Due to the large number of unknown quantities (W_1, Q_2, C_2, and D), equation (5) cannot be solved using standard methods. For this reason and since the data in Figures 9 through 15 are somewhat scattered, no attempt was made to determine accurately the curve equation (5) would describe on each Figure. As a first approximation however, equation (3) can be solved for each data set using the equation of a line which is:

$$Y = a + bX$$

where: $Y = \text{loc } C_3$
$a = \log W_1$
$b = \text{constant}$
$X = \log D$

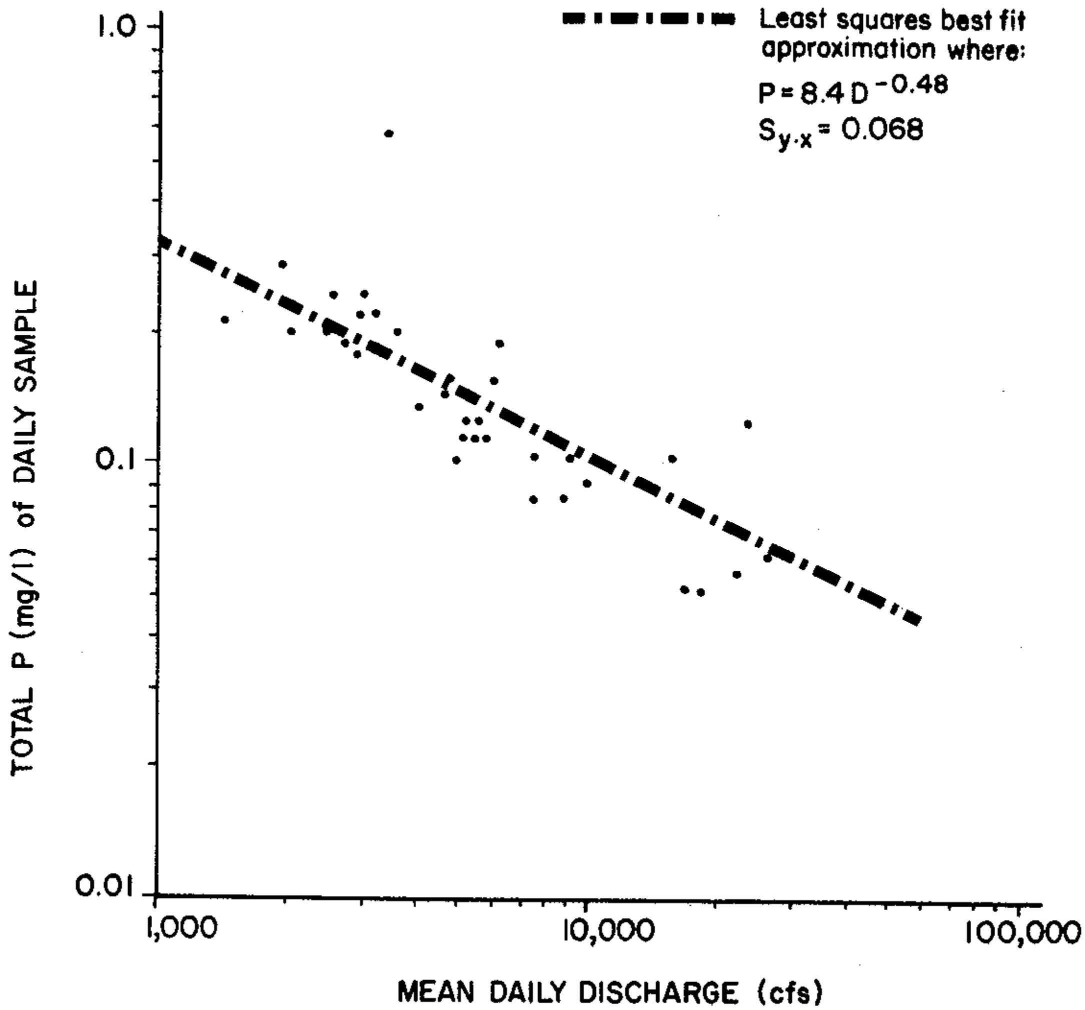
In simpler terms, this relationship is a power curve of the form:

$$C_3 = W_1 \ D^b$$

This equation yields a straight line when plotted on log - log paper.

To investigate flow dependency, the constants W_1 and b were determined for a number of paired water quality-discharge observations by linear regression with least-squares determination of best fit. Figures 9 through 15 present the results of these regressions.

The constants, W_1 and b, which describe the best-fit line are presented on the figures. Additionally, the coefficient of determination (r^2) and the standard error of estimate ($S_{y.x}$) are also presented. The coefficient of determination is a statistical indicator of correlation. If a perfect concentration-discharge relationship existed, the value of r^2 would be one. If no relationship existed, r^2 would equal 0. $S_{y.x}$ is an indicator of the deviation of points about the line much like a standard deviation which measures the deviation of values about a mean. Small values of $S_{y.x}$ indicate that observed data are well explained by the regression. Large values indicate wide scatter in the data.



NOTE: Plots based on 1970–1972 U.S.G.S. water quality data

Figure 9

Discharge vs. Total Phosphorus Water Quality Station 1

Merrimack River Diversion Study

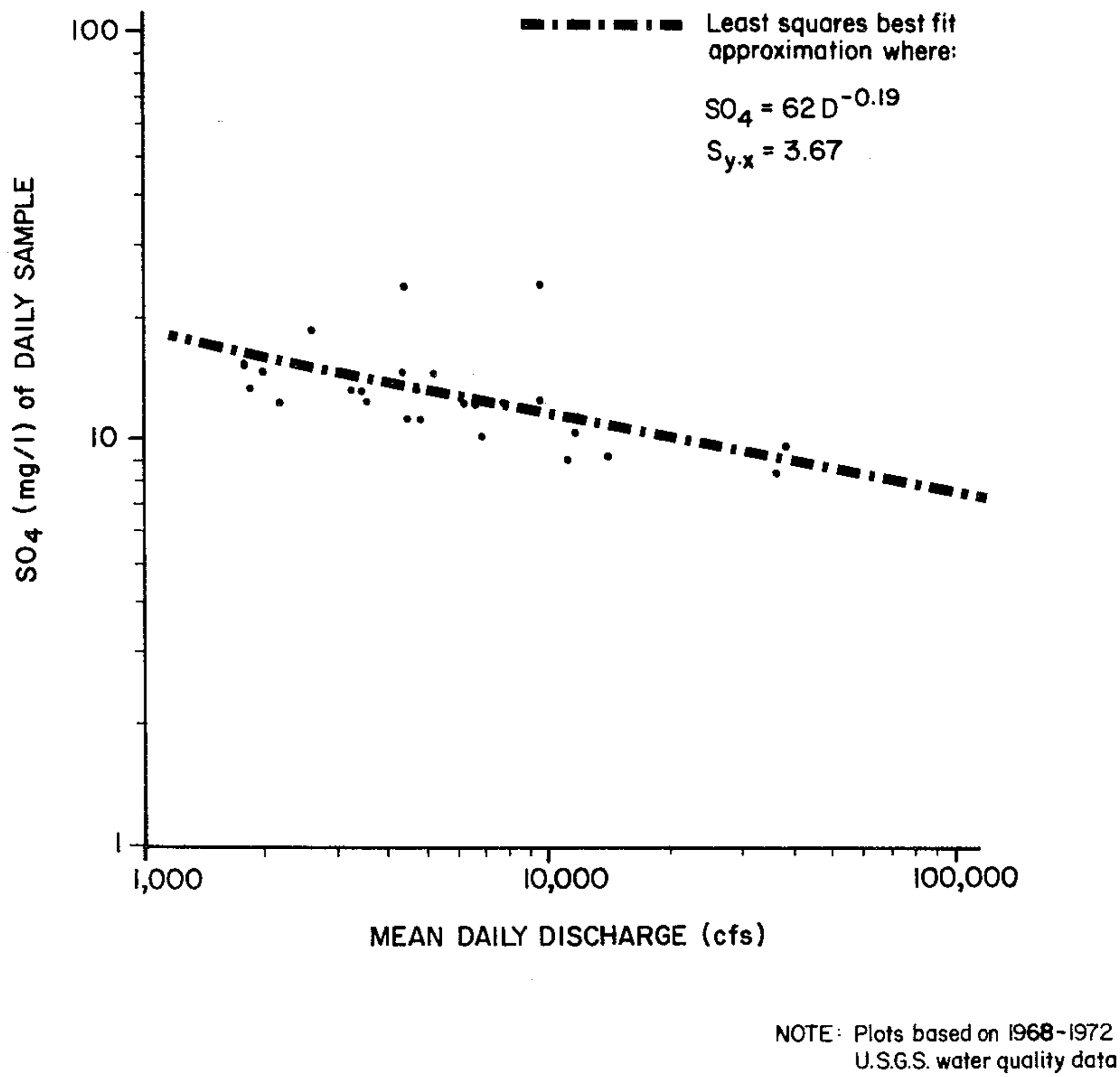
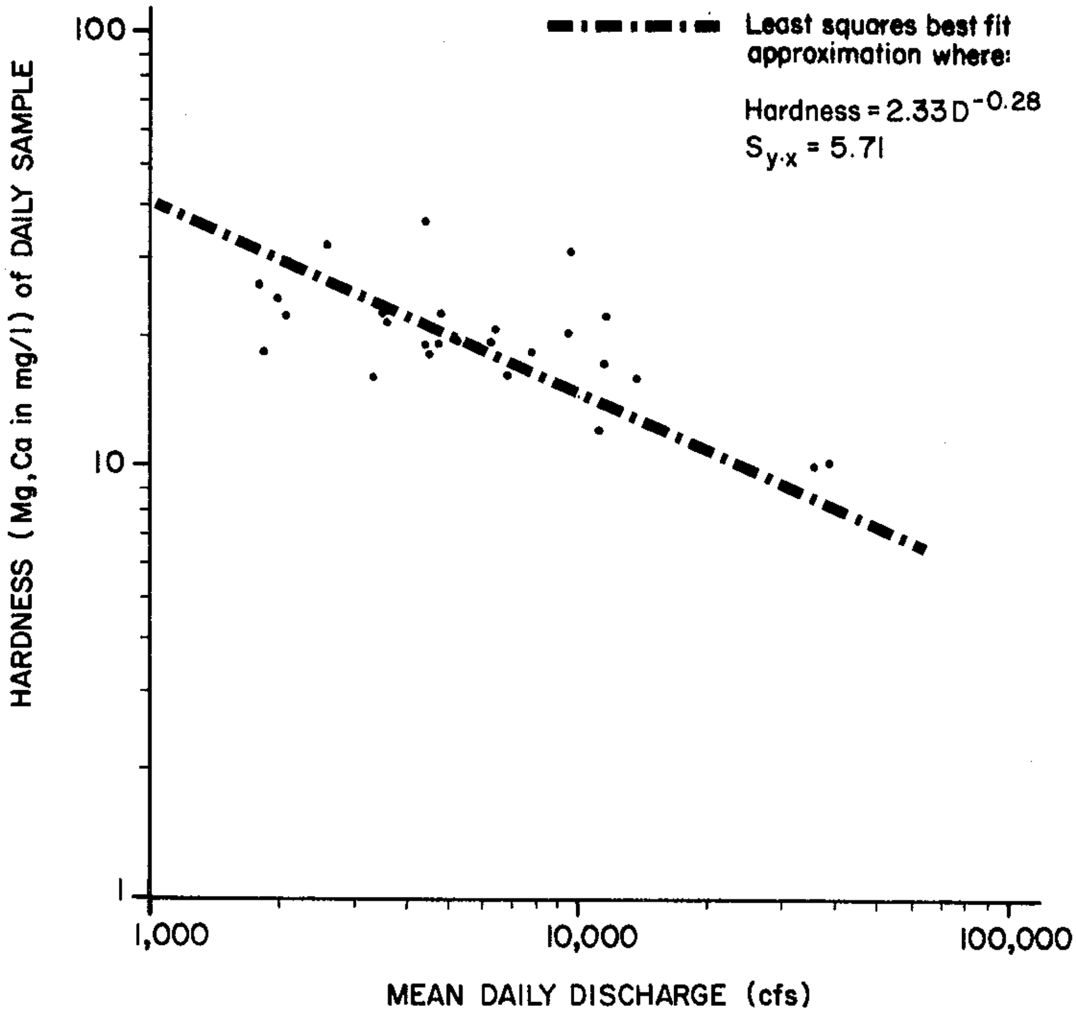


Figure 10

Discharge vs. Sulfate
Water Quality Station 3

Merrimack River Diversion Study

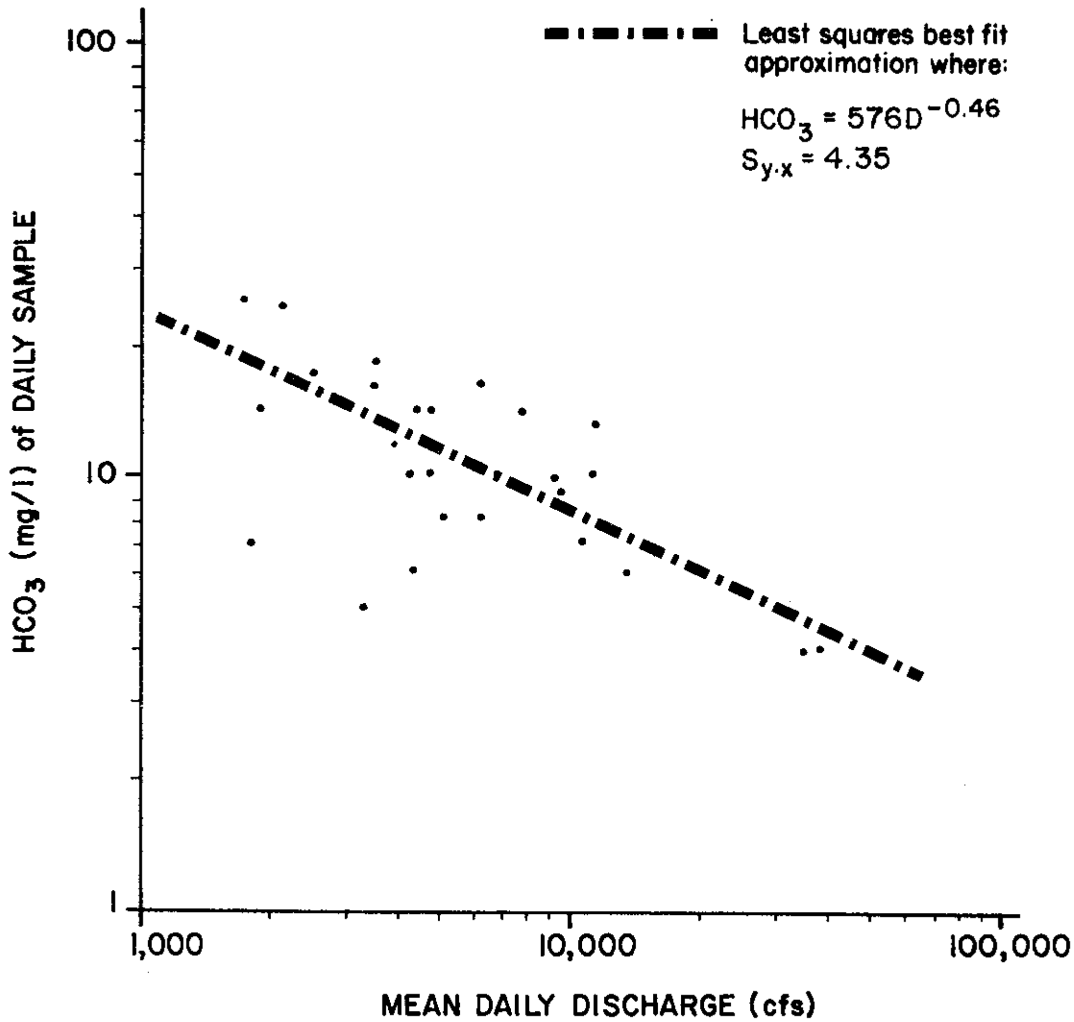


NOTE: Plots based on 1968-1972 U.S.G.S. water quality data

Figure 11

Discharge vs. Hardness Water Quality Station 3

Merrimack River Diversion Study

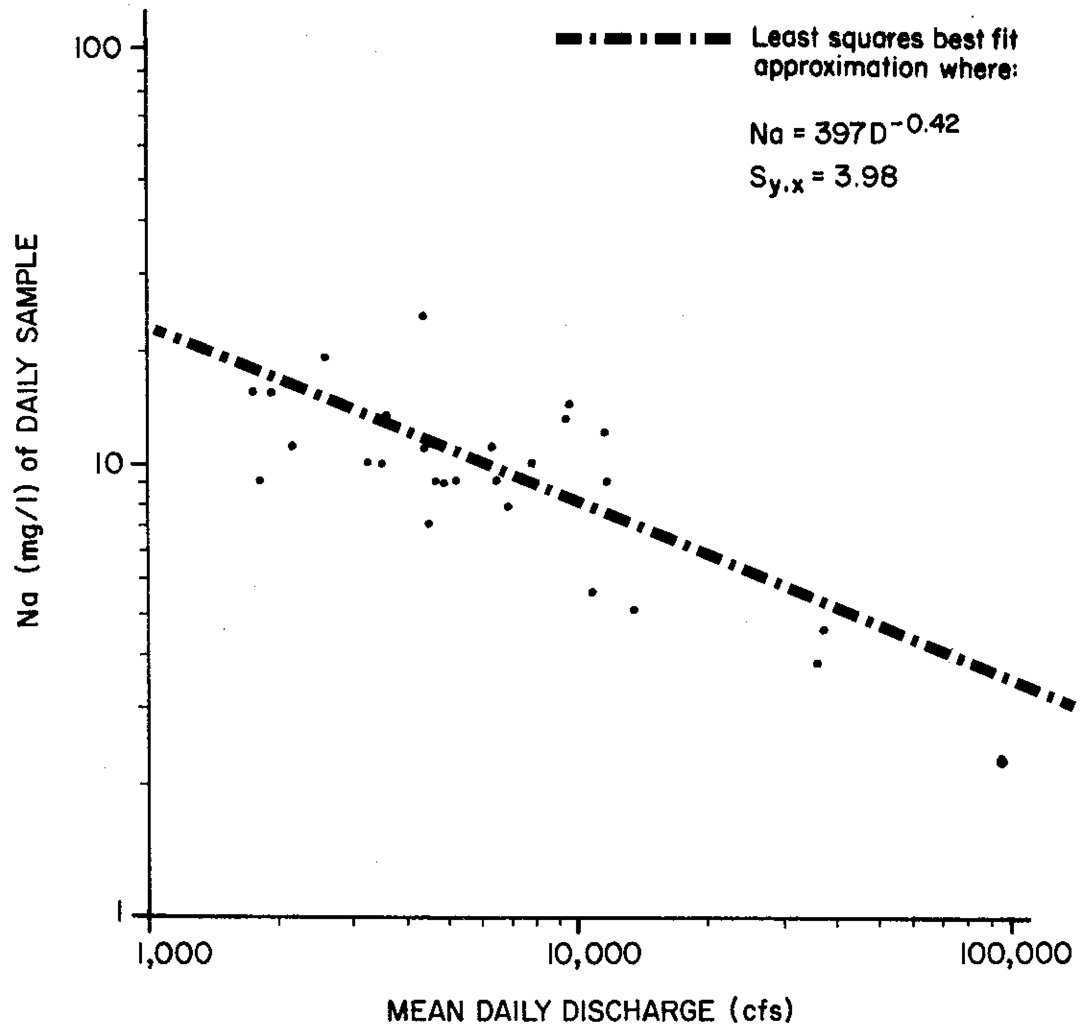


NOTE: Plots based on 1968-1972 U.S.G.S. water quality data

Figure 12

Discharge vs. Bicarbonate Water Quality Station 3

Merrimack River Diversion Study



NOTE: Plots based on 1968-1972 U.S.G.S. water quality data

Figure 13

Discharge vs. Sodium Water Quality Station 3

Merrimack River Diversion Study

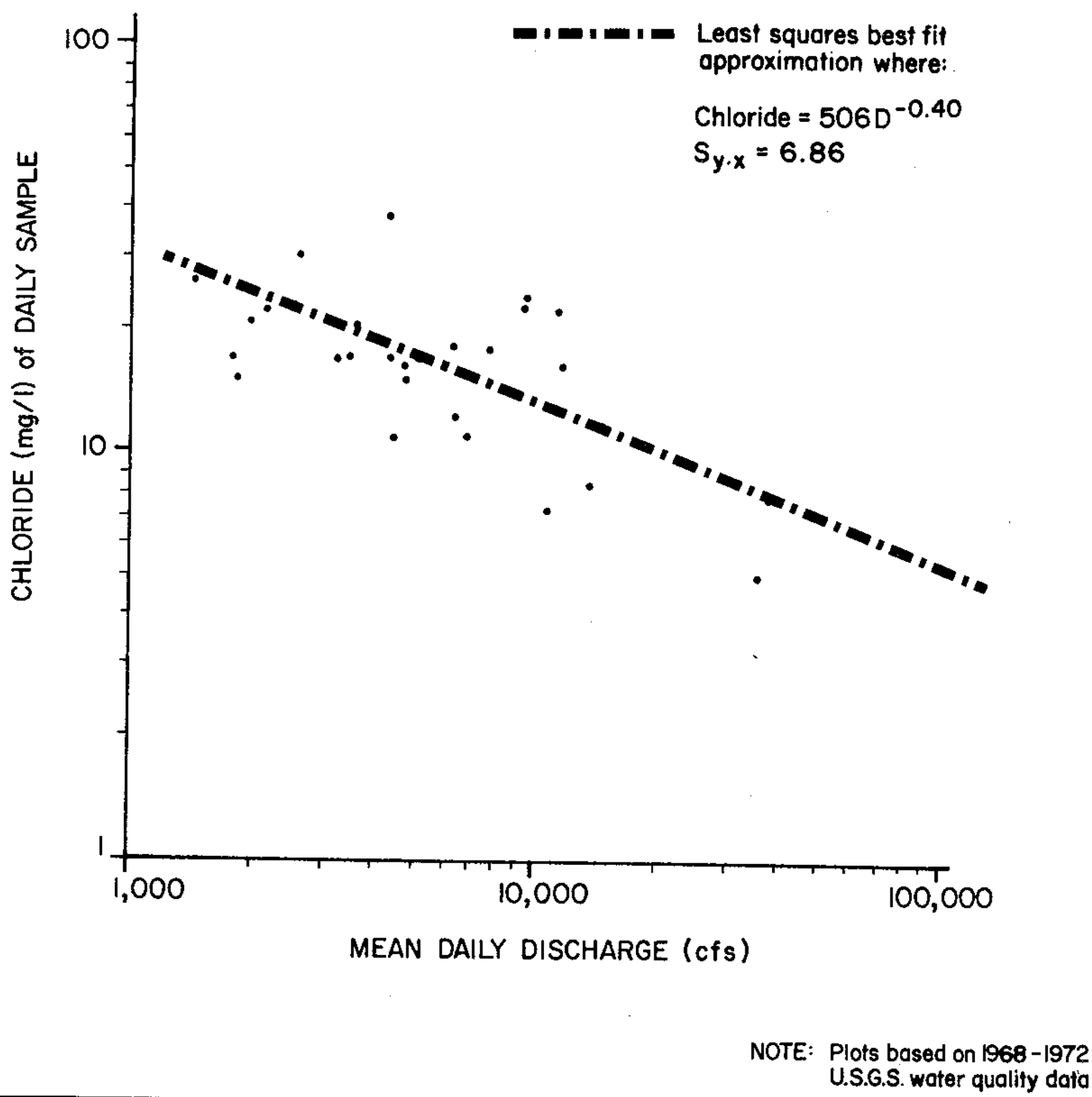
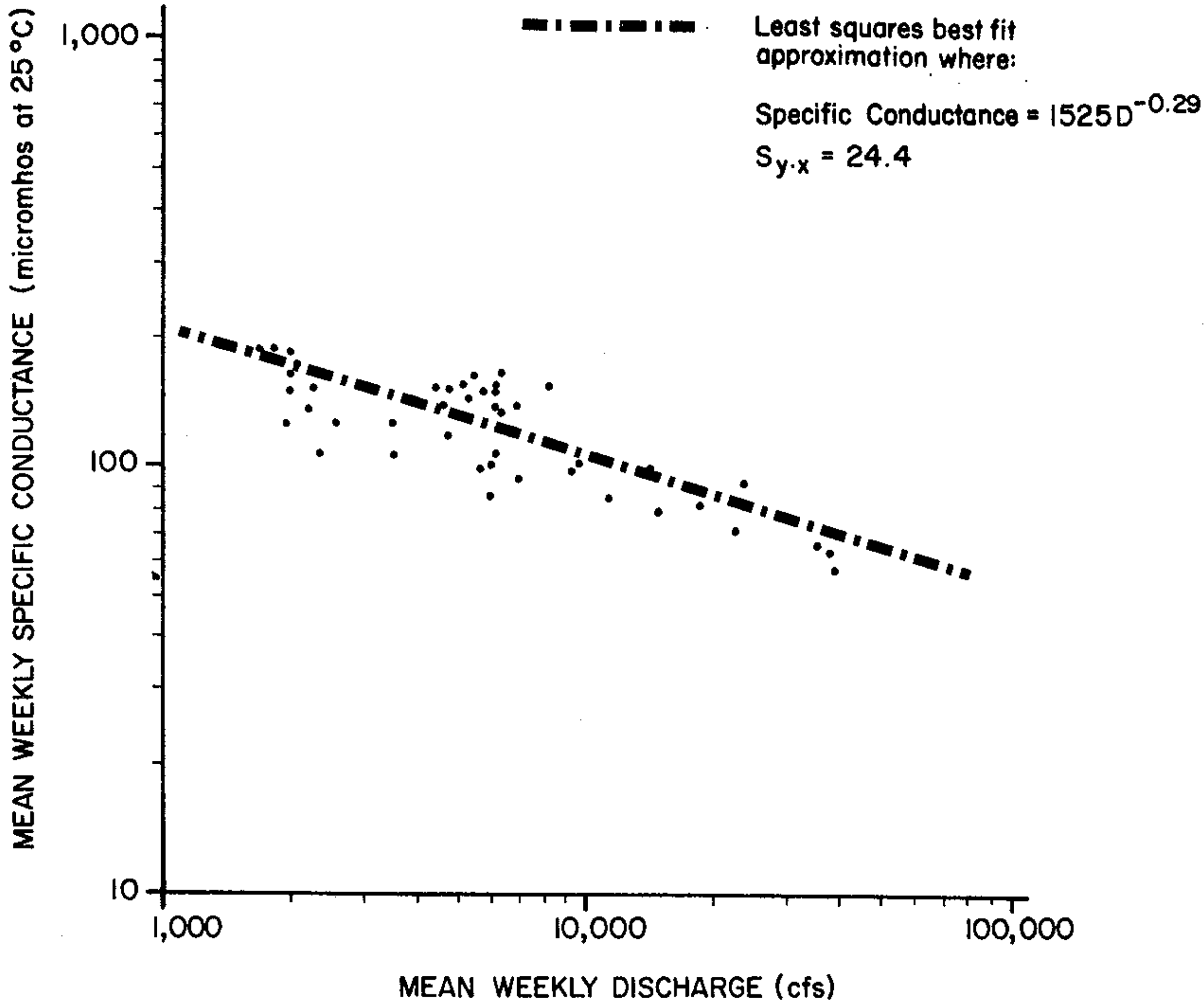


Figure 14

Discharge vs. Chloride
Water Quality Station 3

Merrimack River Diversion Study



NOTE: Plots based on 1969 U.S.G.S. water quality data

Figure 15

Discharge vs. Specific Conductance Water Quality Station 4

Merrimack River Diversion Study

In fact, observed values of r^2 ranged from 0.28 to 0.63 and observed values of $S_{y.x}$ were relatively large compared to the concentrations being considered.

However, it is important that there is a flow dependency and that constituent concentrations decrease with increasing flow. This approximate relationship will be of use in evaluating the flow rates necessary to insure adequate water quality for the restoration of anadromous fisheries in the Merrimack. (Section 5.1)

3.3.4 Seasonally-controlled Parameters

Three parameters were found to be stongly influenced by seasonal climatic conditions: water temperature, dissolved oxygen (DO), and chlorophyll A. As shown in Appendix C, these three parameters rose or fell during the year as the seasonal air temperature changes occurred. Large changes in discharge or unseasonable peak discharge had little or no effect.

Water temperature is, of course, affected by the introduction of industrial wastes, including effluents and cooling waters. However, these changes produce only short-term variations in water temperature. Mean weekly water temperatures plotted against the Merrimack hydrographs are from continuous daily monitoring systems maintained by the U.S.G.S. During any day, the water temperature fluctuations were 1.5°C or less. On a weekly and monthly basis, however, water temperature fluctuations are highly seasonal. The same seasonal fluctuation occurs in each reach. As demonstrated earlier (Figure 8), water temperatures are nearly identical from reach to reach.

Dissolved oxygen (DO) concentrations also showed a marked seasonal variation during the 1968-1973 study period. From the literature it is known that dissolved oxygen concentrations are dependent upon a large number of factors. Hem (1970) states that solubility of oxygen in water is mainly a function of temperature and pressure. The ultimate source of oxygen in water exposed to air is the atmosphere; however a certain amount of oxygen is contributed indirectly as a byproduct of photosynthesis. Surface waters with high organic productivity commonly display wide fluctuations of DO in response to biological activity. Because of the rapidly changing input/consumption rates in surface water bodies, dissolved oxygen undergoes rapid daily changes. For example DO readings taken during the night (when photosynthesis is diminished) differ markedly from readings taken during the daylight hours. Summer daily DO measurements varied by greater than 3.0 mg/l on the Merrimack. Winter readings varied usually by less than 1.0 mg/l. Because of the known high variability of dissolved oxygen levels, continuous measurement of DO over time is necessary to determine possible trends. Hem (1970, p. 221) reiterates this fact also:

> A measurement is meaningful only for the spot of sampling and a brief time period. The oxygen content of a sample of water can readily change after collection and thus must be chemically preserved and determined quickly. The development of electrodes for sensing dissolved oxygen has greatly simplified the sampling and determination problem. This kind of instrumentation was very much needed, and its development represents a major advance in the technology of water quality studies.

U.S.G.S. water quality data used in the Diversion Study did include continuous monitoring data of dissolved oxygen at Reaches 1 and 3. Consequently the determinations of seasonal relationships are considered to be valid. In general, dissolved oxygen during the six year study period was found to vary inversely with seasonal water temperature. This relationship is illustrated in the temperature-DO plots in Appendix C. The seasonal fluctuations appears to be the results of two main factors. First, water is able to hold larger concentrations of dissolved oxygen when water temperature is low. (McKee and Wolf, 1963) Second cold water tends to diminish biological, chemical, and bio-chemical activities which utilize dissolved oxygen. Determining the precise impact of each of the two factors on DO is difficult, especially because of the lack of biological-biochemical data. One water quality parameter that does measure the effect of a combination of biological and bio-chemical conditions is the biochemical oxygen demand (BOD). Preliminary modelling for BOD and DO was conducted during the Merrimack Wastewater Management Study (1974) using a simulation model developed for the Commonwealth of Massachusetts. River coefficients used in the data base for the model were generally obtained from a report done for the General Accounting Office by CAMP, DRESSER & MCKEE, INC. (CAMP, DRESSER & MCKEE, 1969) These studies support the conclusion that dissolved oxygen concentrations decrease with the increased biological and chemical activity that accompanies organic pollution in surface water. In other words, DO decreases with increasing BOD.

Extensive data on BOD were not provided by U.S.G.S. water quality records. However, data on BOD and DO were collected in 1970 at Water Quality Station 3. They were obtained from analysis of 10 DO and 12 BOD samples collected during the year. The DO and BOD data, as well as discharge and water temperature data, are plotted in Figure 16 and serve to merely show the general relationships discussed previously.

The final seasonally-controlled parameter to be considered is chlorophyll A. Concentrations of chlorophyll A were found to fluctuate seasonally in response to seasonal changes in water temperature, as shown in Appendix C. Chlorophyll is a pigment present in the leafy portions of green plants which absorbs red and blue light, the photosynthetically active wavelengths in the visable spectrum. Upon absorption by the pigment, the light energy is converted to the chemical energy used in photosynthesis. In all algae, and in higher plants, chlorophyll A is required for photosynthesis although in some plant groups other chlorophylls such as B, C, and D are also present. Primary production changes during the year, tending to be lowest in the early spring, to increase throughout summer, and to attain its highest levels toward late summer. In the early spring, photosynthetic activity of higher plants is comparatively low, while that of the diatoms is high. This situation reverses itself as the days lengthen and temperature increases. The amount of chlorophyll A present in the water is a good indication of the levels of photosynthetic activity and primary production that are occurring.

3.3.5 Parameters with Unknown Relationships

A total of seven water quality parameters are included in this final category. They include pH, chemical oxygen demand (COD), fecal coliform, nitrogen compounds, potassium, silica, methylene blue active substances, iron, and magnesium. Definite discharge or seasonal relationships were not established for these parameters for a number of reasons. First, some parameters (including (COD, fecal coliform, methylene substances) are highly related to short-term pollution conditions. Consequently they reflect effects of urbanization much more than natural conditions in the Merrimack River. With iron, magnesium, silica, and potassium, either data were lacking to establish a definite natural relationship or the relationship was hidden. In the case of pH, data were abundant because pH was measured on a continuous daily basis. However, pH relationships for any surface water system are highly variable, because pH is dependent

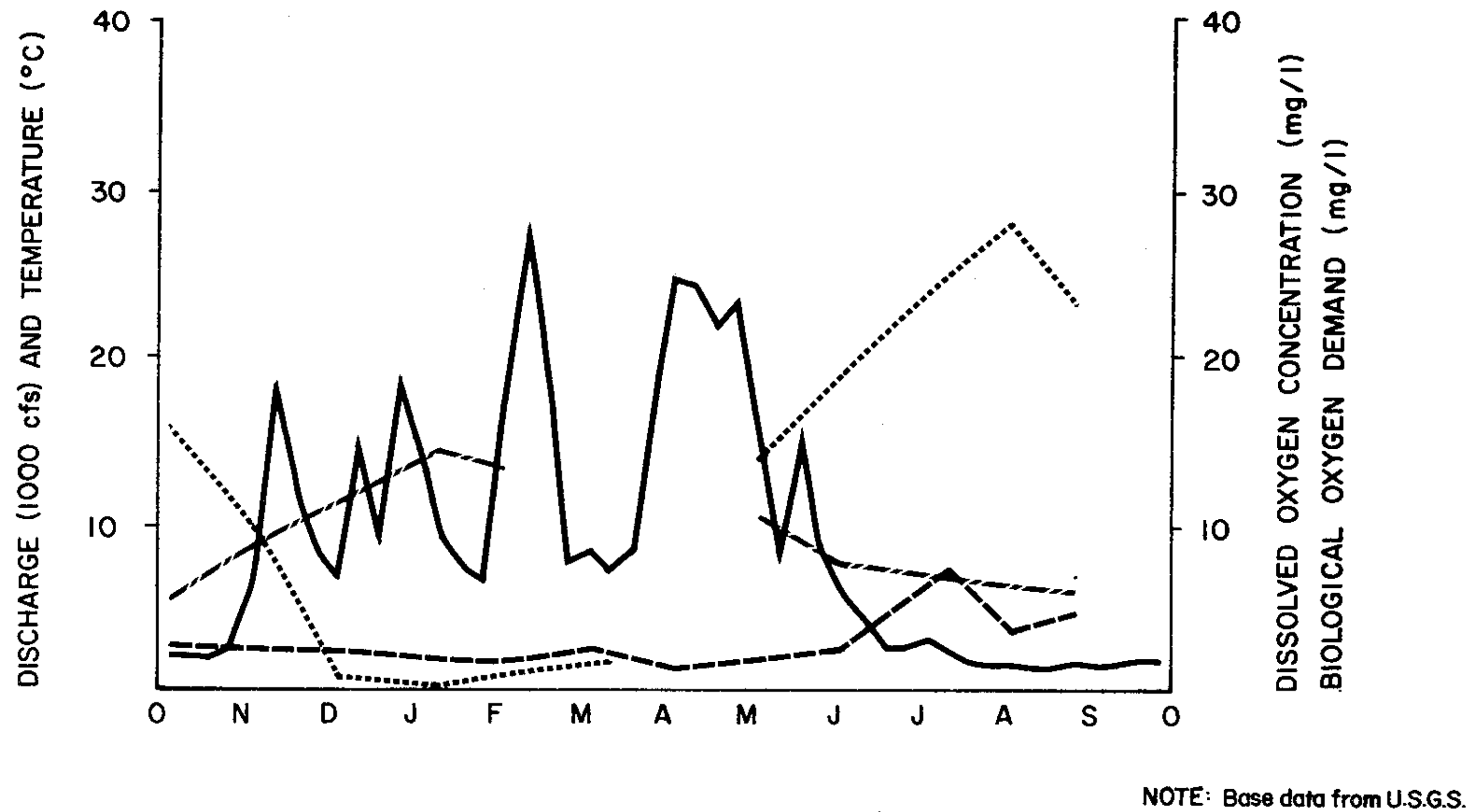


Figure 16

Seasonal Variations of Discharge, Dissolved Oxygen, Biological Oxygen Demand, Water Temperature 1970 Reach 2 Water Quality Station 3

Merrimack River Diversion Study

upon a vast number of natural and human-related influences. The lack of correlation between discharge and these water quality parameters indicates that diversion will not have a major impact on their concentration. The plots do illustrate approximate maximum and minimum values during any given year. These values will be further discussed in Section 5.1 which deals with water quality requirements of anadromous fish.

Minor constituents (primarily metals) and pesticides/herbicides also cannot be assigned any definite flow dependency. The concentrations of heavy metals (See Table 3.4) were not correlated with natural conditions in the study reaches of the Merrimack River because of a general lack of data. U.S.G.S. analysis did include metals determination; however the determination was made only twice each year. Also each semi-yearly determination was made on a composite sample containing 6 individual samples collected during the previous 6 month period. Therefore, the result of the determination is merely the average of the minor constituents. The value is useful, however, because it gives a general indication of the minor constituents concentration in Reach 1 of the Merrimack River. Lack of data prohibits conclusions about minor constituents in Reaches 2 and 3.

Finally, pesticide and herbicide determinations were made for Reach 1 (Station 1) during the period from 1969-1973. During this period, no pesticides or herbicides were detected in any analysis. Again, a lack of data prohibits the generalization that no pesticides or herbicides are to be found in Reaches 2 and 3.

3.3.6 Future Water Quality

Future water quality of the Merrimack River reaches under study will be greatly affected by expected growth in urbanization and population. This will result in major increases in water demand and wastewater production. In the future, wastewater will be disposed of as it has been in the past, that is discharged into tributaries and the main stem of the Merrimack River. It is extremely unlikely that untreated or primary treated wastewater will be discharged into waterways in the future. However, secondary or advanced treated wastewaters are still expected to have an impact on water quality. Secondary-treated wastewater locally increases concentrations of ammonia, chlorine, and metals as well as nutrient levels in receiving waters. These increases are accompanied by increases in BOD and decreases in DO concentrations.

TABLE 3.4

Concentrations (μg/l) of Minor Constituents (metals) at Water Quality Station 1 from 1971-1973. Data from U.S.G.S. 1972 and 1971 Data Based Upon Composited Samples.

	Antimony		Arsenic		Barium		Berylium		Bismuth		Boron		Dissolved Cadmium	
	1*	2*	1	2	1	2	1	2	1	2	1	2	1	2
1973			-	0	13	-	0		<1		9	-	0	0
1972	-	-	-	-	10	10	<1	<1	<2	<1	19	8		
1971	-	-	-	-	18	16	<1	<1	<2	<2	20	19		

	Total Cadmium		Dissolved Chromium		Hexaval. Chromium		Dissolved Cobalt		Total Cobalt		Dissolved Copper	
	1	2	1	2	1	2	1	2	1	2	1	2
1973	-	0	7	0	0	-	<1	0	-	1	12	20
1972			7	4					<2	<1		
1971	<14	<5	10	<10					<1	<1		

	Total Copper		Dissolved Iron		Dissolved Lead		Total Lead		Manganese		Molybdenite	
	1	2	1	2	1	2	1	2	1	2	1	2
1973	10	<10	550/ 110	210	5	2	3	8	72/ 50	30	0	-
1972	10	9	200	130			4	3	61	64	<1	<1
1971	15	18	230	200			13	10	70	67	<1	<1

	Nickel		Silver		Strontium		Vanadium		Dissolved Zinc		Total Zinc		Tin	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1973	4	-	0	-	33	-	<.8	-	10	-	10	-	<1	-
1972	6	3	<1	<1	<11	28	<1	<1			<140	<50	<2	<1
1971	5	5	<1	<1	67	34	1	<1			<40	41	<1	3

	Aluminum		Gallium		Germanium		Lithium		Titanium		Zirconium	
	1	2	1	2	1	2	1	2	1	2	1	2
1973	300	-	0	-	<1	-	1	-	8	-	<2	-
1972	30	130	<1	<1	<2	<1	<10	<10	1	<1	<3	<3
1971	45	510	-	<1	<2	<2	1	1	1	2	-	<1

*1 = Samples taken during first 6 months.
2 = Samples taken during second 6 months.

Fortunately, present Corps of Engineers wastewater treatment plans include provisions for future advanced wastewater treatment. Corps of Engineers computer simulations have been used to evaluate the general impact of various levels of treatment on DO and BOD. (Merrimack Wastewater Management, 1974) The water quality simulation model used was a one-dimensional, steady-state simulation of the Merrimack River system. The model also has an unsteady state portion which accounts for the diurnal dissolved oxygen variation from photosynthetic activity. The model was used to evaluate possible effects of major future wastewater treatment alternatives including: (1) additional wastewater treatment at the New Hampshire/Massachusetts line; (2) advanced wastewater treatment involving partial and complete nitrification.

The basis for evaluation of the two alternatives was a series of assumed water quality conditions in the Merrimack at the state line and in discharged wastewater effluent. With variations and combinations of forms of wastewater treatment, the initial assumed water quality conditions (BOD of 3.5 mg/l, DO of 4.5 mg/l and ammonia concentration of 3.0 mg/l at the stateline in the Merrimack were altered in each reach during flow. The average change over non-treatment conditions per simulated treatment condition is as follows:

(1) Discharge of only secondarily treated effluent from plants below the stateline; no nitrification.

- -Reach 1: DO increased 2 mg/l, BOD decreased 1 mg/l
- -Reach 2: DO increased 3 mg/l, BOD decreased less than 0.5 mg/l.
- -Reach 3: DO increased less than 1 mg/l, BOD decreased less than 1 mg/l.

(2) Discharge of partially nitrified effluent from secondary treatment plants below the stateline only.

- -Reach 1: Same as #1 (Reach 1)
- -Reach 2: DO increased 4 mg/l, BOD decreased nearly 3 mg/l.
- -Reach 3: DO increased up to 3 mg/l, BOD decreased up to 4 mg/l.

(3) Discharge of partially nitrified effluent from secondary treatment plants at and below stateline.

- -Reach 1: DO increased 6 mg/l, BOD decreased 6 mg/l.
- -Reach 2: DO increased 5 mg/l, BOD decreased less than 3.5 mg/l.
- -Reach 3: Same as #2 (Reach 3)

(4) Discharge of completely nitrified effluent from secondary plants below stateline, no nitrification at or above stateline.

- -Reach 1: Same as #2 (Reach 1)
- -Reach 2: DO increased 5 mg/l, BOD decreased less than 3.5 mg/l.
- -Reach 3: DO increased by less than 5 mg/l, BOD decreased less than 2 mg/l.

(5) Discharge of completely nitrified effluent from secondary treatment plants below stateline, partial nitrification at stateline.

- -Reach 1: Same as #3 (Reach 1)
- -Reach 2: DO increased up to 6 mg/l, BOD decreased less than 0.5 mg/l.
- -Reach 3: DO increased by less than 5.5 mg/l, BOD decreased less than 2.5 mg/l.

With the data input used in the Corps simulation model, it is apparent that incremental water quality improvements can be obtained with different levels of wastewater treatment both above and below the Massachusetts/New Hampshire stateline. Of course these benefits will have to be evaluated against the cost of such alternatives.

In another chapter of the wastewater study various degrees of wastewater treatment were applied to anticipated water quality conditions in the Merrimack River for the years 1990 and 2020. The following parameters were considered:

Total Nitrogen	Copper
Organic Nitrogen	Lead
Ammonia	Manganese
Nitrate	Mercury
Total Phosphorous	Nickel
Phenols	Zinc
Cadmium	
Chromium	

With each of these parameters, advanced wastewater treatment improved existing water quality conditions in each of the 3 study reaches. The Corps studies then suggest that if advanced wastewater treatment is implemented in the future, water quality conditions in the Merrimack will improve. The implications of the proposed waste treatment plans for restoration of anadromous fisheries is qualitatively positive. As will be discussed in Section 5, the controlling water quality parameters for anadromous fish restoration are temperature and dissolved oxygen. The future waste treatment plans will insure that future water quality is equal to or better than the current situation. Thus, relationships derived from existing data can be taken as a conservative estimate of 1977 and 1985 water quality conditions.

3.4 Related Environmental Resources and Issues

Certain resources and issues related to the Merrimack deserve ivestigation in order to obtain a better understanding of the influence of the river on its environs. These include wetlands, flooding, navigation, water supply, wildlife refuges and nature study areas, riverside land use, and recreational use of the river. (See 3.5 below)

3.4.1 Wetlands

Some mapping of wetlands has been accomplished by the Merrimack Valley Planning Commission, the Northern Middlesex Area Commission, and municipalities, but these activities have not been coordinated with regard to investigative techniques or scale of mapping. The result is that the data are of variable quality. Certain statements may be made about the wetlands near the river, but site-specific impacts cannot be assessed without detailed field investigations. No wetlands over ten acres in extent occur at the river's edge between the Pawtucket Dam in Lowell and the inland extent of tidal action, although several wetlands are found in close proximity to the Merrimack. There are, however, many river edge wetlands in the tidal portion of the river. In these areas, tidal action is the regulator of water levels. Studies of the estuary (NORMANDEAU and ASSOCIATES, 1971) indicate that river discharge has little or no influence on these wetlands.

With regard to inland wetlands draining into the Merrimack, each was examined to estimate its hydrologic relationship to the river. Only two wetland areas were found to be hydrologically dependent on the Merrimack. Both of these occur in close proximity to the Essex Dam pool in Lawrence. Several riverine wetlands occur along the Shawsheen, a tributary to the Merrimack. Any long-term change in stage at the mouth of the Shawsheen could conceivably, influence its wetlands since its gradient is very gentle.

Each of the other wetlands examined was found to be at an elevation significantly higher than its point of discharge into the Merrimack. The range of elevation difference is

30 to 75 feet. Such a difference indicates that these wetlands are independent of the river and, instead, depend on groundwater flow from adjacent upland areas to maintain their water tables.

In summary, two wetlands, those adjacent to the Essex Dam pool, are felt to be at elevations similar enough to those of the river to be influenced by changes in stage. Such changes are unlikely because of the relatively constant water level of the pool. A third wetland area, that along the Shawsheen, could be affected by long-term changes of stage at its mouth. However, these too are unlikely since this area is subject to tidal water level regulation. Each of the other wetlands was found to be independent of river flow.

3.4.2 Flooding

The spring runoff time presents potential danger from flood damage; the mean peak flow in April exceeds 25,000 cfs. The Army Corps of Engineers estimates that, without the flood control works now in place in Lowell and Haverhill, a recurrence of the 1936 flood would cause damages in these cities of $2.6 million and $4.4 million, respectively. No further construction of flood control works is anticipated in the Merrimack at or below Lowell. Some development may occur within the limits of the 100 year flood in this section of the river, since local zoning in most towns along the Merrimack permits industrial and low density (one acre lots or larger) residential development in these areas. Although no further flood protection works are planned, the new Federal Flood Insurance Program makes flood insurance available to communities within the flood hazard area. An important criterion for eligibility for this Program is enactment of land use and building regulations in the floodplain. Communities which permit new construction or substantial modifications to buildings in the flodplain must require that these structures be of flood-proof design or that the lowest inhabited floor is above the level of the 100 year flood. All communities downstream of Lowell have applied for or are applying for protection under the program, with the exception of the Town of Merrimack.

3.4.3 Navigation

Navigation on the Merrimack is restricted to pleasure craft. The Army Corps of Engineers has made navigational improvements at Newburyport Harbor and from the mouth upstream to

Haverhill for the passage of small craft. According to the Army, recreational boating is continuing to increase between Plum Island and Haverhill, with marina and launching facilities available at six localities in the tidewater reach of the Merrimack. There is also some recreational boating in the dam pools at Lawrence and Lowell.

A potential impediment to navigation exists in the form of sediment which is deposited in varying quantities at different locations in the estuarine portion of the river. According to a study of the Merrimack River estuary (NORMANDEAU and ASSOCIATES, 1971) high flows cause most sediment to be flushed out into the ocean. Under normal flows, sediment deposition is heaviest over Joppa Flats. During periods of low flow sediment is deposited evenly throughout the estuary.

Since most sediment is carried in river discharge rather than by the flood tide (NORMANDEAU and ASSOCIATES, 1971) diversions will reduce the amount of sediment transported to the estuary. Changes in discharge may also affect the pattern of sedimentation in the estuary. If high flows, which normally flush sediment into the ocean, are reduced to normal flows by diversion, sedimentation could be expected to be heaviest over Joppa Flats and less flushing from the estuary could occur. Similarly, reduction of normal flows to low flows could result in sediment deposition throughout the estuary, with potential ramifications to navigational use of the river. Further study is required to quantify the amount and significance of these effects. (NORMANDEAU and ASSOCIATES, 1971)

3.4.4 Water Supply

Water supply is an important consideration for purposes of human consumption, industrial use, and power generation. Table 3.5 indicates the points of water withdrawal and their current capacity and projected needs. It should be noted that most industry along the river obtains its water from municipal supplies or from private wells. By far the largest users of Merrimack River water are the Essex Company canal at Lawrence and the Proprietors of Locks and Canals canal in Lowell. In both cases, the water is used for generating electricity for local industry and returned to the river downstream of the retaining dam.

It should be noted that Lowell is currently discussing the possibility of doubling the capacity of its water system. In addition, Andover recently completed construction of a

TABLE 3.5

EXISTING AND PROJECTED WATER WITHDRAWALS FROM MERRIMACK RIVER

Municipal Water Supply	Present Capacity	1990	2020
Lowell, MA	10.5 mgd	18.4 mgd	22.7 mgd
Lawrence & Methuen, MA	14.5 mgd	21.1 mgd	26.1 mgd
New Hampshire Seacoast Region	-	-	106 mgd
Concord, NH	-	-	36 mgd
Manchester, NH	-	-	55 mgd
Nashua, NH	-	-	87 mgd
Haverhill, MA	-	4.5 mgd by 2008	
Andover, MA	-	11 mgd	18 mgd

Industrial Use

Haverhill - Haverhill Boxboard Company. Current withdrawals 4 mgd.

Lawrence - Essex Company Canals Hydroelectric plant. Requires a minimum of 2000 cfs. Current needs are about 3500 cfs peak.

Lowell - Proprietors of Locks and Canals - Require a minimum of 3500 cfs.

Sources: NH figures from Merrimack River Basin Plan, New Hampshire Water Supply and Pollution Control Commission, Staff Report No. 56, February 1972.

Haverhill and Andover figures from Army Corps of Engineers and are for maximum day demands, interpolated from the communities' engineering reports.

Industrial figures from personal communications.

new water treatment plant with a design capacity of 12 mgd or 18.5 cfs and a maximum expansion capability of 24 mgd or 37 cfs. North Andover draws its water from municipal wells and has no current plans for direct withdrawals from the Merrimack; however this new plant represents a possible future water requirement. Current municipal water withdrawals represent a drain of about 38 cfs on the Merrimack. 1990 needs are projected to require about 77 cfs. By 2020, the Massachusetts communities may require about 110 cfs and New Hampshire communities may draw as much as 430 cfs.

3.4.5 Wildlife Refuges

Two island bird sanctuaries are present in the Merrimack in Salisbury. These are the Carr Island and Ram Island Sanctuaries, both owned by the Massachusetts Department of Natural Resources. The DNR does not actively manage these islands and knows little about their resident animal populations.

3.4.6 Riverside Land Use

Throughout the study area the river and its environs are recognized as actually or potentially important recreational assets. Fishing, boating, hiking, nature study and aesthetic enjoyment currently occur and may be expected to increase in the future. At the present time mud flats in certain areas and the general assumption by people that the river is badly polluted cause the river to be less used than it might otherwise be.

Present zoning and "Future Land Use" plans prepared by the regional planning agencies of the study area indicate that land use along the Merrimack will, in the future, contain a mix of open space, low density residential, and industrial uses. Several sewage treatment plants are either under construction in Haverhill, Amesbury, Lawrence, (Greater Lawrence Sanitary District serving Lawrence, Methuen, Andover and North Andover) and Lowell. Newburyport has an existing primary treatment plant to be upgraded to secondary while Billerica has a secondary treatment plant in operation on the Concord River. Each of these plants is designed to meet state water quality criteria in their respective receiving waters, assuming a ten-year, seven-day flow. As long as diversions from the Merrimack do not cause these flow conditions to increase in frequency, no adverse effects should be felt on the River from the treatment plants. (Mass. Department Natural Resources, personal communication). Riverfront projects currently being considered include state parks in West Newbury and in Lowell, along the canals. The DNR indicates that discharge requirements for recreational purposes in and along the Lowell canals are actually less than those for power generation. Plans for the West Newbury Park are currently dormant.

3.5 Commercial and Recreational Uses

3.5.1 Past Use

During the colonial and early national periods the Merrimack River was of considerable commercial importance. It was used as a highway for the transport of masts, timber, and lumber, for example. As late as 1845, when the Massachusetts General Court issued a charter to the Essex Company permitting it to dam the main stem of the river at Lawrence, Massachusetts, the article of incorporation required the company to provide a canal for toll-free passage of masts and rafts to timber and lumber around the dam. (ch. 163, 1845)

The lower stretch of the river consists of a tidal estuary some 26 miles long, extending from the mouth at Newburyport to the head of tidewater at Haverhill. Newburyport was a major harbor and shipbuilding center during the clipper ship days, with activity centering on the protected waters of the estuary. The harbor is currently of minor importance, being used primarily for small boats and for delivery of petroleum products.

There was also an extensive commercial fishery carried out in the river from the earliest days of settlement. Like most major river systems, the Merrimack appeared to the colonists to offer an inexhaustible supply of fish. These included both anadromous species such as salmon, shad, sturgeon, smelt, and alewives and oceanic visitors to the estuary such as menhaden, striped bass, sea bass, mackerel, and flounder among others. Excessive fishing pressure led to threats to the supply and attempts to regulate the fishery as early as 1734. (ch. 8, 1734) Such regulations of the fishery on the Merrimack and its tributaries continued well into the 19th century.

The salmon fishery went into sharp decline after construction of a dam near Bristol, New Hampshire, which cut off access to the chief salmon spawning grounds on the Pemigewasset River. The shad fishery remained important until construction of the Essex Dam at Lawrence in 1847. (Oatis, 1969) While the Essex Company was required by its charter of incorporation to build and maintain a fishway, technical deficiencies prevented maintenance of a significant salmon or shad fishery after damming of the mainstem at Lawrence and Lowell. In addition, water pollution associated with textile mills at these locations further damaged the fisheries. (ch. 163, 1845) (Oatis, 1969)

3.5.2 Present Use

Except as noted above, there is little commercial use of the river today. However, significant numbers of oceanic species which are commercially and recreationally important, such as clam worms and stripers, still frequent the estuary. Severe pollution and the dams have virtually eliminated species of commercial value from the River above the Essex Dam. A study conducted by the Massachusetts Division of Marine Fisheries in 1965 estimated the value of the commercial fishery in 1964 at $123,475. (Jerome et al) This included a clam harvest ($14,000) which is no longer permitted because of pollution of the beds and a lobster fishery ($13,500) both in the estuary proper and in the estuary-influenced ocean area directly off-shore of the river mouth. Adjusting for these changes would leave the estuarine fishery's value at at least $100,000 in 1964 dollars; accounting for changes in the purchasing power of the dollar would suggest that the same level of effort would produce a commercial fishery return of about $160,000 in 1974. In view of rising food costs, the current value could well be higher. Future improvement of water quality in the river and the estuary should lead to further increases in the value of the commercial fishery. For example, it was estimated in 1964 that the soft shell clam fishery in the estuary, which had a harvested value of $14,000, could be worth at least $300,000 per year were the flats not closed because of pollution. (Jerome et al) Assuming clean-up of the river, and the same level of harvest, this fishery would be worth about $480,000 in 1974 dollars. Withdrawals for water supply above Lowell should have no significant influence on the estuary and its commercial fishery because of the over-riding influence of ocean waters on this part of the river.

There also is a significant sports fishery in the Merrimack estuary. Again, the species sought are not resident fish but oceanic visitors such as striped bass, blackbacked flounder, mackerel, pollock. The 1964 value of this fishery (based on measured expenditures for charter fees, boat hire, bait purchase, and so on) was estimated at $326,670. (Jerome et al) Translated into 1974 dollars, the same level of effort would suggest a value of about $523,000.

The 1965 study by the Marine Fisheries Division also offered an alternative estimate for the value of the sports fishery in the estuary which took account of those fishing from the shore as well as those using boats. It was suggested that during 1964 there were slightly more than 100,000 fishermen days which were valued at the then current rate for salt water fishing of $10.00 per day. This led to a value for the sports fishery in excess of $1,000,000. (Jerome et al)

While the estimated expenditures of $10.00 per day may have been somewhat high in relation to actuality in 1964, it would certainly be very conservative for 1974. At the same time, recreational fishing has been increasing much more rapidly than population in recent decades. For example, between 1944 and 1959 the population of the United States grew by 32% while the number of licensed fishermen increased by 140%. (ORRRC #7, 1961) Between 1960 and 1970 the numbers of Americans 12 years or more of age increased by about 18%; the number of recreation days devoted to summer month fishing during this same period increased by almost 61%. (National Survey, 1970) If one assumes a similar growth in sport fishing in the Merrimack estuary between 1964 and 1974, there would be about 163,000 recreation days dedicated to this fishery in 1974. At $10.00 per day, this yields a recreational value of about $1,500,000 for this fishery. However, the value of a salt water fishing day along the Atlantic coast was slightly greater than $10.00 in 1970. Adjusting the inflation since then, one might expect the value of the 1974 fishery to be on the order of $2,200,000.

The proposed diversion should have little or no impact on this sport fishery. However, the value of the sport fishery should increase markedly over the next decade as the results of improvements in water quality and of the re-establishment of anadromous fish runs in the Merrimack system. Revival of substantial runs of alewives will produce a modest increase in commercial fishery values and should attract additional predators such as striped bass, already an important component in both the existing commercial and sport fisheries. Re-introduction of significant salmon and shad runs will add considerable value to the sports fishery, especially in the non-tidal portions of the river where there is currently almost no angling activity. This fishery could be threatened by excessive or poorly timed diversion of main stem waters above Lowell. The economic values at stake will be discussed below in Section 4.4.

4.0 ANADROMOUS FISH

4.1 Historical Presence of Anadromous Species in the Merrimack River

Historically, the Merrimack River provided spawning grounds for several species of anadromous fish. Pollution and the construction of numerous dams have caused the virtual elimination of annual runs of fish in the Merrimack. The Essex Dam in Lawrence (mile 29) was completed in 1847. However, because of an inadequate fish ladder the annual migration of fish was halted. (Oatis and Bridges, 1969)

Alewives, Alosa pseudoharengus; shad, Alosa sapidissima; Atlantic Salmon, Salmo salar; and sturgeon, Acipenser oxyrhynchus were once commonly caught in the Merrimack as they made their annual spawning runs. The short nosed sturgeon, Acipenser brevirostrum, may have used the Merrimack, but virtually all recent U.S. records are from the Hudson River. Hundreds of thousands of pounds of shad were caught annually in the Merrimack before the erection of the Essex Dam (Bigelow and Schoreder, 1953). Because of available spawning grounds below this dam, shad were able to maintain a small run until 1896 (Bigelow and Schroeder, 1953) However, unrestricted fishing and discharge of domestic and industrial wastes into the river resulted in the eventual elimination of shad from the Merrimack River. (See Table 4.0)

Salmon spawned only in the tributaries of the Merrimack in New Hampshire. Thus, the construction of the Essex Dam resulted in the complete elimination of salmon runs by 1859. The lower Merrimack was occassionally visited by stray salmon until 1901, but since that time the presence of salmon in the Merrimack has been rare. (Bigelow and Schroeder, 1953)

Sturgeon were once abundant in the Merrimack River. (Bigelow and Schroeder) During the 17th century, sturgeon were so plentiful that commercial enterprises exported them to England. Overfishing and the age required for sturgeon to become sexually mature, 10 years, have contributed to the depletion of stocks. Dams and water pollution are additional factors that have contributed to their decline. Occasionally, sturgeon still enter the Merrimack. Bigelow and Schroeder (1953) noted the report of a 230 lb. sturgeon which was landed in Newburyport on September 14, 1938.

The alewife, once very numerous in the Merrimack, has also been virtually stopped from its migration by numerous dams

TABLE 4.0

Shad Catches in the Merrimack, 1789-1896

Year	Number of shad caught, reported, or estimated
1789	830,000
1805	540,000
1835	365,000
1865	50,000
1871-1873 (average)	1,942
1880	2,139
1885	130
1888	None
1889	18
1890-1892	None
1893	2,020
1894	2,750
1895	94
1896	7

Source: Bigelow and Schroeder, 1953

on the main stem and its tributaries. At one time, alewives ascended as far as Lake Winnepesaukee. Today, only a handful are able to maneuver past the Essex and Pawtucket Dams. The New Hampshire Department of Fish and Game (1971) reports that on May 27, 1971 eight alewives of the 10" - 12" size range were captured below Amoskeag Falls. More alewives were observed in this location until June 5, 1971. The very similar requirements and appearance of the alewife and blueback herring suggest that the blueback historically used the Merrimack River System for spawning. Even today alewives and blueback herring are numerous in the Merrimack estuary. (Jerome et al, 1965)

Although rainbow smelt and striped bass have been caught in the lower Merrimack River, whether these species have ever used the river for spawning is questionable. Cutter (1885) mentions that smelt fishing was good in the Merrimack. Today the striped bass is still a common visitor to the Merrimack estuary, and a sizeable sport fishery exists there for that species. (Jerome et al, 1965)

4.2 Restorable Species

4.2.1 Identification of Anadromous Species Considered for Potential Restoration to the Merrimack River

According to the Technical Committee for Fisheries Management of the Merrimack River Basin, there are seven species of anadromous fish currently under investigation to determine potential for restoration to the Merrimack River. Each is viewed as potentially restorable for commercial or sport fishing because of historical presence and/or chances for successful establishment in the river. Species being considered for restoration are: the alewife, *Alosa pseudoharengus*; shad, *Alosa sapidissima*; blueback herring, *Alosa aestivalis*; Atlantic Salmon, *Salmo salar*; Atlantic Sturgeon, *Acipenser oxyrhynchusoxyrhynchus*; striped bass, *Morone saxatilis*; and smelt, *Osmerus mordax*. The shortnose sturgeon (a. *brevirostrum*) is not being considered for restoration owing to its endangered status and to the paucity of information regarding its habits and requirements, even though it may be present in New England waters. It is believed that improvement of the river to the extent that restoration of these species is made possible will also result in the usage of the Merrimack by other anadromous and catadromous species such as the lamprey, *Petromyzon marinus*; American Eel, *Anquilla rostrata*; and the white perch, *Morone americana*. Of the potentially restorable species, active programs exist only for the Atlantic Salmon and the shad.

4.2.2 Factors Influenceing the Establishment of Anadromous Fish in the Merrimack River

Numerous dams along the Merrimack River and its tributaries are the principal cause for the virtual absence of anadromous species from this watershed. The dams prevent migrating fish from reaching their spawning grounds. In addition, pollution by industrial and domestic wastes have also contributed to their elimination.

Dams

Historically, the Merrimack River system provided extensive spawning ground for a variety of anadromous fish. The N.H. Fish and Game Department has surveyed the watershed, and reports that, even today, there are 7,212,857 square yards of streambed that are considered to be suitable nursery habitat for Atlantic Salmon. This survey defined suitable nursery habitat as boulder or rubble-bottomed riffle areas. Pools and slow water areas were excluded from the area determinations. Fishery biologists estimate that approximately 3 smolts can be produced per 100 square yards of nursery habitat in the Merrimack River watershed. (Newell et al, 1963) It is further estimated that smolt survival until adulthood should approximate 5 percent. These figures indicate that the Merrimack watershed has a potential for a run of 10,820 adult salmon.

Because adults return principally to their natal rivers to reproduce, anadromous fish runs depend upon the successful production of young or the repeated introduction of juvenile forms. Thus, to sustain a natural population of anadromous fish, it is necessary to provide access to areas of reproduction.

A survey was conducted by the New Hampshire Fish and Game Department to determine the presence of obstructions which can limit the movement of salmon in the Merrimack Watershed. A total of 56 man-made dams and 2 natural falls were cataloged (Newell, 1963). Biologists conducting this survey stated: "The survey only progressed as far upstream as there was sufficient nursery habitat to warrant the construction of fish passage facilities at obstructions." (Newell et al, 1963) To restore the watershed to its full potential (10,820 salmon), fish ladders were recommended for installation at approximately 37 of the 56 dams cataloged. The remaining 19 dams were either provided with passage facilities or not in use and in ruins. Breaching those dams which were in ruins was recommended.

Passage facilities are also necessary to allow the movement of shad, alewives, and blueback herring. The spawning grounds for shad are confined primarily to the mainstem of the Merrimack from the limit of freshwater to Lake Winnepesaukee, plus a few of the tributaries in the lower river basin. (Oatis, 1969) Restoration of the shad fishery would require installation of fishways in dams located in the mainstem. Because the alewife is more capable of negotiating fish ladders than shad (Bidelow and Schroeder, 1953), it is believed that provision for the passage of shad and salmon will help to restore runs of alewife and blueback herring.

Pollution and Effects of Diversions

Pollution has been a major factor contributing to the decline of anadromous fish populations in the Merrimack. Newell and Nowell (1963) state that pollution loads in the Merrimack definitely constitute a barrier to migrating fish. Present water quality must be at least maintained and, if possible, improved in order for successful restoration of salmon and shad to occur.

Diversion of large volumes of water from the Merrimack River could be deleterious to possible future runs of anadromous fish. Should proposed diversions occur, care must be taken to insure that chemical and physical requirements of the seven anadromous species are maintained. The chemical and physical requirements for each species are presented in the individual life history treatments in Appendix D and are discussed further in Section 5.1. Figure 17 summarizes the anticipated presence of the various anadromous fishes in the Merrimack. It should be noted that this figure is an idealization and represents a synthesis of anadromous fish behavior data from many sources. (See Appendix D) As discussed later in this section, natural conditions will present some limits to species presence.

Diverting of water can affect the homing, spawning success, and juvenile development of all anadromous species. Increased volumes of water discharged from a river during spring and autumn stimulate the migratory behavior of adult and juvenile fish. If these seasonal peak flows (freshets) do not occur, fish are delayed from migrating. Such a delay to migrating salmonids can cause stress resulting in reduced productivity. (Oglesey et al, 1972) (Hoar, 1953)

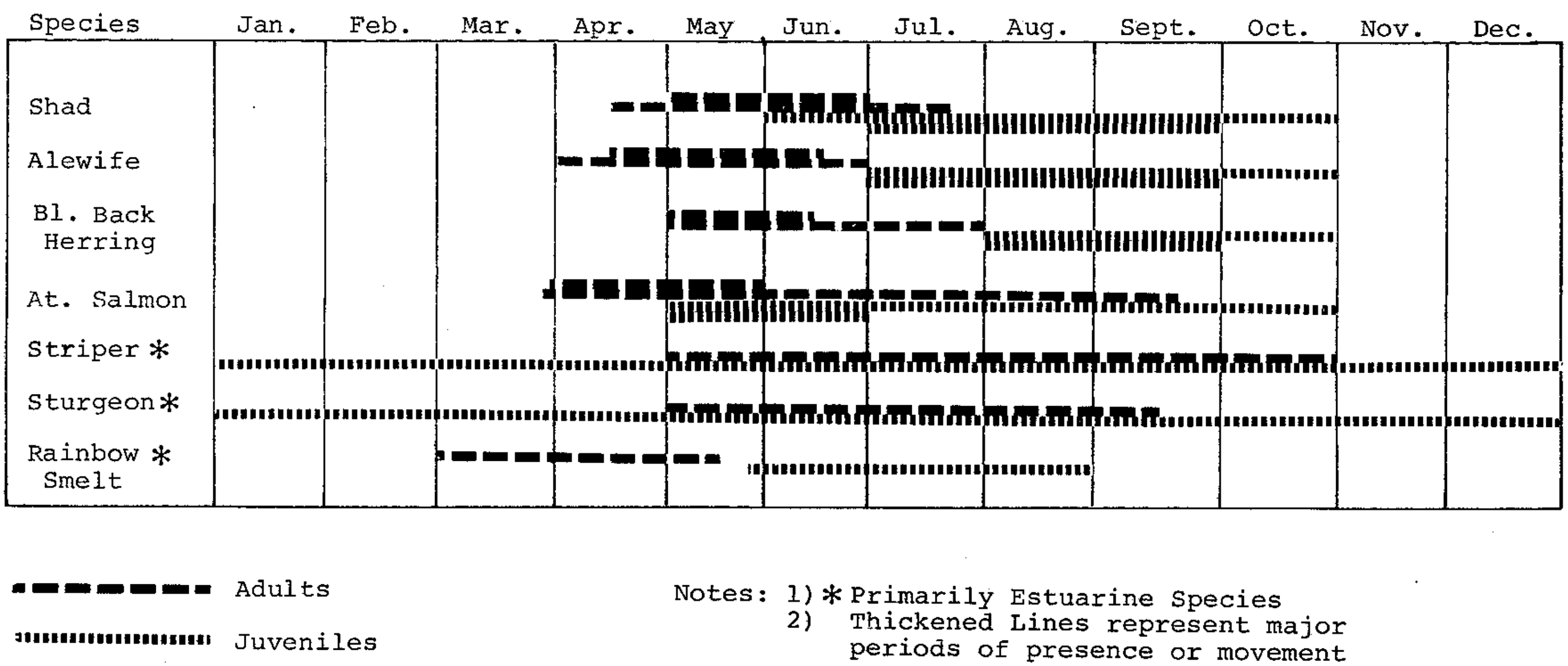


Figure 17

Presence of Anadromous Restoration Species in Study Area

Merrimack River Diversion Study

In discussing the migration of Sockeye Salmon in the Frazer River, Andrews and Green (1960) state:

> ....during years of low spring and summer run-off, the period delay off the mouth of the river is extended and migration occurs over a longer period of time and at a later average date. In such years, the fish in the last part of the run often do not arrive at the spawning grounds or arrive too late for efficient spawning.

Alabaster (1970) has analyzed the relationships between yearly flow in the Coquet River and the accompanying run of Atlantic Salmon. His data suggest that a positive correlation does exist between the annual discharge and the total number of salmon entering the Coquet River during a given year. Smoker (1953) noted that a positive correlation existed over a 15 year period between the annual discharge of rivers in western Washington and the annual total commercial landings of Coho Salmon.

The preceeding studies suggest that large diversions of water from a river could limit the size of a run of salmon. In a personal communication, Meister indicated that if the volume of discharge in a river were reduced this would probably result in a small run of salmon. However, the exact relationship between discharge and the size of a run is not known. In studies on the Connecticut and Hudson River, no correlation was found between shad abundance and flow (Essex Marine Laboratory).

An excessive diversion of water could be detrimental to those species which spawn in the lower reaches of the Merrimack River. Shad, sturgeon, and (possibly) striped bass are species that are known to have spawned historically in areas affected by the proposed water diversion. Factors which must be considered for maintaining the lower Merrimack River as a potential spawning area of these species include depth, water velocity, and water quality.

Diversions of water could also cause changes in the water quality of a river. Various chemical and physical parameters such as temperature, dissolved gas concentrations, pH, and concentrations of various pollutants may be flow dependent. Fish are sensitive to changes in these parameters. During August and September, discharge over dams in the lower Merrimack River approaches zero. During these months, water temperatures in the lower Merrimack are such that a temperature barrier is formed which inhibits the upstream movement of adult salmon. For this reason, it is believed that movement of salmon during these months will be confined primarily to the downstream movement of smolts.

Changes in temperature can have several effects. Temperature increases can result in lowered productivity or even mortality of spawning fish because of changes in the rate of ovary development. Should egg development occur too rapidly, spawning will commence before the fish has had sufficient time to reach suitable spawning grounds. Other consequences of increasing natural water temperatures include increase in consumption of dissolved oxygen and use of body reserves. Oxygen consumption of salmonids doubles for every increase of 10°C in water temperature. (DeCola, 1970) This might prove critical if dissolved oxygen concentrations are at a minimum. Similarly, Brown (1957) reports that consumption of body reserves in migrating fish doubles with every 10°C rise in temperature. This is because metabolism in poikilothermic animals increases with increased temperature. It has been suggested that the high incidence of shad mortality in Florida and Georgia is attributed to the relatively high temperatures of southern rivers. (Essex Marine Lab) Thus it can be seen that precautions must be taken to insure a temperature range which is suitable for anadromous fish populations.

In summary, the chemical and physical requirements of anadromous species must be maintained for all life stages which are present in the area affected by the proposed diversion of water. For salmon, water quality in the lower Merrimack River need be suitable only during the migratory stages. For species spawning in the study area, the requirements of all stages of development must be met throughout the reproductive cycle.

Restoration Potential

Introducing various age groups by successive year stocking is important for the successful restoration of anadromous fish in the Merrimack River. Stocking programs can result in future fish runs only if certain requisite measures (construction of fishways, pollution abatement, and regulation of water diversions) are also implemented. Upon establishment of the runs, care must be taken to insure their continuation. Regulations on sport and commercial fishing must be instituted; and enforcement of these rules is essential.

If the above-mentioned measures are taken, restoration of salmon, shad, blueback herring, and alewives should prove feasible. (See Sections 6.2 and 6.3) Whether or not striped bass and smelt ever spawned above the Essex Dam is not certain; therefore, any impact on populations of these species is difficult to estimate. However, because the striper is an important gamefish in the Merrimack estuary, care must be taken not to jeopardize its presence.

The Atlantic Sturgeon is listed by the New England states as an endangered species (Miller, 1972). Overfishing of a species that requires 10 years to attain sexual maturity is a contributing factor. It is not known whether sturgeon are able to manuever over fish ladders. Because there has been little work done pertaining to the restoration of Atlantic Sturgeon, and because of the scarcity of the species along the Atlantic coast, it is doubtful that sturgeon runs will return to the Merrimack River in the near future.

Catchability

Anglers' success in catching anadromous fish, should restoration prove successful, depends upon several factors. These include numbers of fish present, water temperature, and stream velocity. Fishery biologists from New Hampshire and Massachusetts have estimated the amount of nursery habitat in the Merrimack watershed, and from this have computed the expected size of salmon and shad runs. It is believed that the Merrimack River has a potential run of 10,820 adult salmon and approximately one million adult shad.

Water temperature and velocity influence the willingness with which salmon take bait or artificial lures. Meister (personal communication) states that the optimal temperature range for successful salmon fishing is 12° - 18°C, and that an increase in flow rate will increase catch. DeCola (1970) states that "...temperatures above 20°C severely restrict success in fishing for adult salmon, and approximately ten days of reduced water temperatures is required before the fish will again respond to angling."

Anadromous fish generally do not feed during their upstream movement, although Meister (personal communication) states that salmon can be caught during their first 3 weeks in fresh water. In the Connecticut River, the principal sport fishing for shad occurs on their spawning grounds. (Essex Marine Lab, 1972) Stomach analysis of shad in freshwater indicates that shad do not feed prior to spawning (Walburg, 1960), and it is thought that perhaps shad strike at artificial lures in an attempt to defend their spawning grounds. (Walburg, 1960) (Mansueti & Kalb, 1953)

It can be concluded that proposed diversion of water from the Merrimack River could affect catchability of anadromous fish in two ways. It may limit the number of fish in the river, or it could raise temperatures above the optimum range for successful salmon fishing.

4.3 Restoration Programs

4.3.1 Brief History of Merrimack Fishery Restoration

During the first century of the English colonization of New England, the abundance of fish in the harbors, bays, rivers, streams, and lakes was so great as to astound the settlers who were accustomed to the much lesser resources of old England. The annual runs of anadromous fish were a special source of wonder. They supported a substantial fishery for both domestic use and for export to Europe and to the Caribbean. (Wood)

However, by early in the 18th century there began to appear signs that a resource which had seemed inexhaustible was, in fact, finite. Part of the trouble lay in the damming of smaller streams leading to spawning places to provide necessary power for saw and grist mills. Massachusetts enacted laws governing such obstructions and regulating the use of weirs and other fish trapping devices. These general acts failed of their purpose, however, leading to enactment of special statutes governing fisheries on particular rivers and streams. Among these was the Merrimack.

In October, 1733, a number of inhabitants of towns along the Merrimack asked the General Court to take such action as would "be most effectual for the preservation of the fish passing up the great River Merrimac." (Mass H. of R, Journal, 1733) A special act governing the Merrimack fishery was passed the following July. The preamble to the statute noted that weirs had stopped fish from ascending the river and caused them to abandon it, noting a special loss of "bass and sturgeon which are very valuable." (ch 8, 1734) The purpose of the act as stated in the preamble was clearly to bring about a restoration of former conditions in the Merrimack fishery by eliminating undue fishing pressure which prevented anadromous fish from reaching their natural spawning grounds.

This act was renewed in 1737 and remained on the books for ten years thereafter. (ch. 4, 1787) It was allowed to lapse because New Hampshire refused to regulate the salmon and shad fishery on its part of the river. In 1750 the Merrimack was the best salmon river in New England, pollution from saw mills and dams having greatly damaged the fisheries on the Piscatoway and other rivers in Maine. (Birkett) In 1759 New Hampshire finally moved to regulate the salmon and shad fishery within its borders. (Weeden) and Massachusetts enacted a new special statute regulating the Merrimack fishery in 1765. (ch. 24, 1765) This statute, as later amended, was the organic act protecting and regulating the Merrimack fishery until after the Revolution. (ch. 30, 1766; ch. 45, 1773; ch. 32, 1774)

Attempts to preserve the Merrimack fisheries through legal restrictions continued into the 19th century. Between 1783 and 1820, for example, the Massachusetts General Court enacted no less than 17 distinct laws relating to the Merrimack. (Handlin) The fishery in question was, of course, almost wholly a commercial operation. By the time angling for salmon was introduced into the United States in the 1830s salmon had nearly disappeared from southern New England. (Goodspeed) After 1820 the salmon run was greatly reduced by a New Hampshire dam which cut off access to the chief spawning grounds on the Pemigawasset. (Oatis, 1969) The shad fishery was of major commercial importance in the 1830's. (Smith) Construction of the Essex Dam in Lawrence, followed a few years later by the Pawtucket Dam at Lowell, spelled the end of natural salmon and shad runs in the upper Merrimack. (Oatis, 1969)

There were fishways provided at these two major obstructions on the mainstem and there were repeated and continuing attempts to restore and maintain a salmon and shad fishery through improvement of fish ladders and artificial stocking of upper river spawning areas. These efforts achieved some slight success, with a cooperative program undertaken by the Massachusetts and New Hampshire Fish Commissions providing the impetus for the program. (Mass. Fish Comm. Reports, 1867, 1868, 1869). However, on the whole, results were disappointing. Mainstem and tributary dams and industrial pollution proved to be too much for the anadromous fish above the Essex Dam, though a significant fishery continued in the estuary until near the end of the 19th century. As late as 1882 the fishery near Chain Bridge in Newburyport was sufficient to support a force of 30-40 men manning 11 seines in boats - with the catch limited to salmon, shad, and a few alewives - during the months of May, June, and July. (Goodspeed) By 1893 the Merrimack fishery was restricted almost entirely to alewives, sea herring, and menhaden. No salmon were reported in the catch for that year, while the immense quantities of shad common at an earlier time had dropped off to a catch of 2,020 fish (out of a total of 18,474 for the entire Commonwealth.) The Massachusetts Commissioners of Interior Fisheries and Game reported in that year that salmon were passing Essex Dam and reaching New Hampshire waters, only to be stopped by obstructions above and below Concord. (Annual Report, 1893) The last report of a significant number of salmon below the Essex Dam was in 1896; no running salmon have been seen in the river since 1901. (Bigelow and Schroeder)

Early attempts to maintain and re-establish the salmon and shad fisheries in the Merrimack were doomed by the greed of commercial fishermen, lack of cooperation between New Hampshire and Massachusetts, the growth of industry, and a lack of adequate technology. These conditions having changed, the success of a future restoration program seems much more likely than the experience of the 18th and 19th centuries would indicate.

4.3.2 Current Programs

Fish and game departments from Massachusetts and New Hampshire are interested in restoring the runs of anadromous fish, especially salmon and shad, to the Merrimack; both departments have instituted programs to accomplish this end. Fisheries personnel of New Hampshire and Massachusetts and representatives from the U. S. Bureau of Sport Fisheries and Wildlife and the National Marine Fisheries Service have met on several occasions to discuss the restoration of anadromous fish to the Merrimack River. These agencies have established the Technical Committee for Fisheries Management of the Merrimack River Basin to carry out research programs and to develop management procedures for the re-establishment of salmon and shad fisheries in the Merrimack River.

Experts on fish passage facilities from the West Coast joined fisheries personnel from New Hampshire and Massachusetts in visits to existing obstructions in the mainstem of the Merrimack. The visual observations of the various dams led to optimism over the prospects of the Merrimack River Anadromous Fish Restoration Project. The Pawtucket Dam in Lowell, Mass. and its adjacent canal system represent the greatest obstacle to restoration attempts. A report concerning the visit by West Coast biologists states, "...it is felt the problems are minimal compared to those which have been encountered and resolved on the West Coast." (Newell and Nowell)

Massachusetts

The Massachusetts Department of Fish and Game conducted four field studies on the Merrimack River between June 1968 and November 1971. These studies were concerned primarily with surveying the fish populations and physical characteristics of the river.

A fishery survey on the Massachusetts section of the Merrimack revealed that the river contained mostly trash fish. Carp, Cyprinus carpio and suckers, Catostomus commersoni comprise 81.8% of the total weight of resident species. The report concluded that warm waters of the lower Merrimack preclude the establishment of a cold water fishery except as a migratory route during spring and autumn. The fish survey report also included a survey of water chemistry.

A second study was conducted to determine the suitability of the Merrimack River for development of shad eggs and juveniles. Shad eggs were incubated in the Merrimack over a 3 year period, from spring of 1969 through spring 1971. Approximately 2 1/2 million fertilized eggs were planted in hatching boxes in the river upstream from Lowell, Mass. The eggs were inspected periodically to determine incubation success. Unfortunately, vandalism to hatching boxes prevented hatch estimations during 1969 and 1970, but 80% of those planted in 1971 hatched successfully. Electroshock sampling gear and trawling apparatus was employed in an effort to recover juvenile shad; however, none were recovered. Their absence is attributed to the small size of the egg stock used and the relatively small number of juveniles probably produced as a result. However, the success in hatching shad eggs indicates that the water quality in Reach 1 of the Merrimack River is suitable for the production of shad.

Other studies by Massachusetts include the cataloging of obstructions to fish passage in the Massachusetts section of the Merrimack basin and mapping of the physical characteristics of the mainstem between Newburyport and the New Hampshire state line.

New Hampshire

The New Hampshire Fish and Game department has conducted studies similar to those in Massachusetts. Fishery surveys have been conducted on the mainstem of the Merrimack River. In the river below the Amoskeag Dam it was found that brown bullheads, *Ictalurus nebulosus*, and white suckers, *Catostomus commersoni*, comprise 70% of the total number caught. In the area above the Amoskeag Dam, yellow perch, *Perca flavescens*, and pumpkinseed sunfish, *Lepomis gibbosus*, predominate. In the upper reaches of the Merrimack River golden shiner, *Notemigonus crysoleucas*, is the most common fish. Perhaps the most significant result of the fishery survey was the capture in 1971 of several alewives below the Amoskeag Dam. This capture proved that water quality in the lower Merrimack River is not an insuperable obstacle to upstream migration of certain anadromous fish species during spring.

Shad eggs have been hatched successfully in incubation boxes placed in the river during successive summers since 1969. Hatching success has ranged between 19 and 88% with a mean success of 66% for the period 1969 through 1972. The reduced success observed at certain times during this period has been partly attributed to unripe parental stock. Success in hatching shad eggs in the Merrimack River is further evidence of the suitability of the existing water quality during the spring months.

Juvenile shad were caught in the New Hampshire section of the Merrimack during September and October of 1971 and 1972. This is conclusive evidence that the New Hampshire section provides an adequate nursery area for the juvenile phase of the American Shad.

As noted above (Section 4.2.2), New Hampshire biologists have cataloged barriers to the passage of anadromous species.

4.4 Recreational and Commercial Importance

4.4.1 Commercial

Restoration of anadromous fish runs to the Merrimack could have some commercial significance. At one time the Atlantic sturgeon was an important component in commercial fisheries in New England. (Bigelow and Schroeder) While sturgeon are occasionally captured today in the Gulf of Maine, their numbers are so small as to preclude an organized fishery at present. Those caught by chance have little market value. (Fish. Stat.) This could change, however, in the event of a substantial increase in the sturgeon population that would permit a concerted effort to bring them to market on a regular basis. All indications are that Merrimack sturgeon would be limited to the estuary and to streams entering it below the Essex dam. (Knight) Accordingly, there is little reason to expect that diversions would have any real impact on the fishery, whose restoration will be almost entirely dependent upon improvements in water quality.

Much the same can be said for smelt. Smelt are limited in their ability to climb streams of steep gradient. They almost certainly will not pass the proposed fishways at Lawrence and Lowell in any great numbers. Any new smelt fishery will, therefore, probably be wholly or almost wholly confined to the estuary and its tributaries. (Knight) Smelt are caught by hook and line and thus also represent a potential angling resource, as well as a marketable product. But, as in the case of sturgeon, diversions upstream will have an insignificant impact on any smelt fishery as compared to the effects of improving water quality.

Better water quality and more efficient fishways over major dams will undoubtedly add to the success of alewives in reaching spawning areas. (Even today some alewives manage to make the run up the Merrimack over poorly designed fishways as far as Manchester, New Hampshire.) (Knight) It is difficult to estimate the value of this potential fishery. Enormous numbers of alewives were taken prior to the near destruction of the fishery by pollution and dams. The Merrimack system might easily support a fishery of a million pounds or more. At a commercial value of perhaps fifteen cents a pound, this could add up to something over $150,000 a year (Fish. Stat.) While a commercial fishery might well be concentrated in the estuary, there would be some opportunity for harvest upstream and in tributaries. The fishery could be affected by excessive withdrawals with impacted unfavorable on water temperatures or other critical factors during migration up and down stream.

4.4.2 Recreational

There are as yet no firm estimates of the impact of anadromous fish restoration program on the commercial fisheries discussed briefly above. The main planning emphasis has been on bringing back the salmon and shad runs. This planning is taking place wholly in the context of a sports fishery; no commercial fishing has been contemplated as yet, although it seems likely that there would be pressure for such a fishery (perhaps especially for shad) if current objectives of the program are realized. (Newell and Nowell) (Knight)

Those objectives call for establishing an annual run of Atlantic Salmon of approximately 11,000 adult fish from the ocean toward the spawning grounds. For shad, the goal is a run of 1,000,000 spawning age fish. If current timetables are met, the salmon run will be sufficiently established by 1980 to support a brood stock program, while a limited sports fishery should be available by 1985, and the full anticipated run of 11,000 salmon should be realized by 1990. The shad run timetable should be roughly comparable. It is expected that anglers will be able to capture from 15 to 25% of the migrating salmon and about 20% of the shad. (Newell and Nowell) (Knight)

Since the diversion program could, at some withdrawal rate, put this program in jeopardy, it is important to estimate the value of the resource at stake. In the discussion that follows the shad and salmon fisheries will be discussed separately, since they have quite different characteristics which will be reflected in their economic importance when considered as recreational resources.

<u>The Salmon Fishery</u>

Salmon fishing is, by and large, an elitist, upper-income sport. It requires large initial expenditures for equipment, special clothing, and the like. A serious salmon fisherman might lay out $500.00 for such expenditures prior to leaving for his first visit to a salmon river. (Knight) Moreover, capture ratios are low; it has been estimated that once the Merrimack run has become fully established it will require 20 days of fishing effort for each salmon captured. (Preliminary Summary) The fishery attracts those with both a love for this perverse sport and the resources in time and money required to support their hobby. Those who do engage in it have demonstrated willingness to travel great distances -- from New York to Nova Scotia or New Brunswick, for example. Thus, the river salmon fishery hardly appears to represent the kind of enterprise that will attract small boys or the local fishing buff who likes to cast a line in a local body of water with a reasonable expectation of catching his dinner.

The special characteristics of the projected salmon fishery in the Merrimack make it extremely difficult to determine its economic value. There is little experience to serve as a guideline, so it becomes necessary to make projections from available data on other fisheries. For example, the salmon fishery will undoubtedly attract many non-residents, but it is impossible at this time to estimate the proportion of non-residents to total anglers engaged in the fishery with any precision. The New Hampshire lake salmon fishery, which is more nearly akin to the river salmon fishery than any other, attracts about 62% residents and 38% non-residents. (NH F&G) There is no comparable fishery in Massachusetts, with the possible exception of salt water angling which also attracts a large number of non-residents. For purposes of analysis, it will be assumed here that non-residents will provide about 60% of the fishing effort and residents the remaining 40%.

It is also difficult to allocate expenditures geographically. There will be fishing opportunity along the entire river, including the estuary and the dam pools above Lawrence and Lowell in Massachusetts, but only experience will show where the actual fishing will be concentrated. (Knight) Daily expenditures for food, drink, lodging, car rentals, supplemental gear, and so on will be reflected in local economies. Fixed capital investments may be made primarily out of the region, even by residents, though it is possible that there will be some opportunity for local sporting goods houses to share in some of this bounty. For these stated reasons, the economic importance of the salmon fishery will be treated as a whole, with no real attempt to break out local or regional impacts. However, a rough rule of thumb might be that, whatever the proportion of residents to non-residents, probably about half of the expenditures will be made in the region.

In the calculations that follow, the value of the fishery will be expressed as a total for capture rates of 15% and 25%. The values will be derived by employing a variety of plausible criteria.

For example, the commercial (wholesale) value of fresh Atlantic Salmon is about $1 per pound. (Fish. Stat.) While the fish caught may range from 6 pounds to 35 or more, it is anticipated that the average salmon landed will weigh about 10-12 pounds. The 10 pound value will be assumed here. At commercial prices, this would yield a fishery value of from about $16,000 to about $27,000. These values are felt to be absurdly low.

Some estimates are based on an average expenditure by salmon fisherman of $10 per pound. (Newell and Nowell) This would yield fishery values of from $160,000 to $270,000. However, the $10 per pound price was orginally derived from Canadian experience about 1960. If one were to assume that this is a valid measure but adjust for inflation in the intervening years, the value in 1974 dollars would be $16.80 per pound. This would make the value of the fishery something between $271,000 and $450,000 for capture rates in the range 15 - 25%.

The standard measure for freshwater fishing stipulated for the Department of the Interior by the Office of Management and Budget for cost/benefit calculations in $6.00 per fishing day. (Knight) Assuming that 20 days of effort are required for each fish captured, this would yield fishery values between about $198,000 and $330,000. Recent studies show that in the United States as a whole freshwater fishermen averaged expenditures of $6.30 per day in 1970. (National Survey) Translated into 1974 prices, this would amount to about $8.07 per day and yield fishery values between about $266,000 and $444,000.

However, the basic rate being employed here is undoubtedly too low. In 1970 salt water fisherman expended an average of $10.77 per fishing day (National Survey) which amounts to about $13.79 in current prices. Since the salt water fishery is much closer to the river salmon fishery than is most freshwater fishing in terms of required expenditures for equipment, travel, food, lodging, and so on, this would appear to be a more realistic figure to use. The values of the fishery for a 15% and 25% capture ratio would then become respectively, about $445,000 and $759,000 respectively.

Analyses of the fishery for lake salmon in Lake Winnisquam in New Hampshire offer yet another possible set of values. The value per fish caught in terms of expenditures appears to be (in 1971 prices) $71.50 for a resident and $156.18 for a non-resident. (Knight) Tranlated into 1974 dollars, these amount to $87.75 and $191.67 respectively. If we assume that non-residents account for 60% of the river fishery and residents 40%, the value of the fishery for a capture rate of 15% would be about $248,000 and for a capture rate of 25% about $413,000. A different split between resident and non-resident activity would change these results to some extent.

The basic New Hampshire data indicate that resident fisherman spent $11.88 per day in fishing for lake salmon, while non-residents spent $25.95 per day, both in 1971. (NH F&G) Translated into 1974 prices these would amount to expenditures of $14.58 and $31.85 per day, respectively. If we assume similar expenditures for the river salmon fishery and a ratio of one fish per 20 days effort as before, we arrive at the following ranges of values for the fishery. If all would be about $481,000 for a 15% success rate and about $802,000 for a 25% success rate. If all were to be taken by non-residents, the corresponding values would be about $1,051,000 and $1,752,000 respectively. However, neither of these assumptions are particularly realistic, since both residents and non-residents will engage in the fishery. If the fishery is arbitrarily split between non-residents and residents on a ratio of 60/40, the value for a 15% capture rate would be about $823,000 while for a 25% capture it would be about $1,372,000.

The value of the sport fishery for migrating river salmon is thus clearly difficult to judge and quite dependent upon one's assumptions. The range for a 15% capture rate is from about a low in the neighborhood of $250,000 to a high of nearly $900,000. For a capture rate of 25% the corresponding values are about $440,000 and $1,400,000. The low values are probably too low and the high values may be unrealistically high. Perhaps a reasonable estimate could be found by taking an average. This would yield about $575,000 for the 15% catch and $920,000 for the 25% catch. Of this, at least half would probably be spent in the region.

The Shad Fishery

It is anticipated that the shad fishery, if re-introduction is as successful as anticipated, will present quite a different picture from the salmon fishery. The runs will be large -- on the order of 1,000,000 spawning adults in a typical year. Catches are estimated at 20%, or 200,000 fish. The required fishing effort will be low and is estimated at one fish per recreation day. (Preliminary Summary) Massachusetts experience in the Connecticut below the dam at Holyoke suggest a capture rate of one fish in about three hours from a boat and in about 6 hours from the shore. (Mass F&G) Required outlays to enter the fishery are minimal, perhaps on the order of $12 for a spinning rod and a shad spoon. (Knight) In contrast to the salmon fishery, shad should attract local residents anxious to combine sport with a decent chance at augmenting the family diet.

This attraction would be particularly strong in the Merrimack Valley region. In general, the area suffers from a depressed economy, in both Massachusetts and New Hampshire.

For example, analysis of 1970 census data for the Massachusetts cities and towns bordering the river reveals the following. Unemployment in 1970 was running at a rate of about 4.3% for both male and female members of the labor force. The unemployment rate for males was lowest in Tyngsborough (2.7%) and for females in Newbury (2.1%). High unemployment for males (6.1%) was found in Newburyport and for females (7.4%) in Merrimack. Throughout the region 7.8% of all persons were found to have incomes below the poverty level, ranging from 2.1% at Chelmsford to 16.8% in Newburyport. Family mean incomes were uniformly higher than family median income. For the region, family mean income was $11,703 with a range from $9,038 in Salisbury to $16,595 in Andover. The regional median family income was $10,635, with a low of $8,950 in Salisbury and a high of $14,400 in Andover. Average income per capita was $3,206 for the region. In Salisbury it was $2,547, while in Andover it was $4,458. By way of comparison, the average per capita income for Massachusetts in 1970 was $4,340. Of the cities and towns studied, only Andover had a per capita income higher than the average for the State. While similar analyses have not been carried out for New Hampshire cities and towns along the Merrimack, it is believed that the findings of such an analysis would be quite similar.

New Hampshire residents tend to engage in fishing more than Massachusetts residents, reflecting a twenty fold greater abundance of fishable waters in the more northern state. In 1960, studies showed that 22% of the New Hampshire population held fishing licenses, while in Massachusetts the corresponding figure was only 4%. (ORRRC #7, 1961) Since 1960, fishing has greatly expanded as a form of recreation in the United States. (National Survey) However, in Massachusetts cities and towns bordering the Merrimack the number of all fishing licenses (resident and non-resident) was about one for each 26.4 people. Thus, the 1974 participation rate for licensed fishermen in the region in Massachusetts is below the 4% figure for the State as a whole in 1960. This low rate undoubtedly reflects both general low economic status which would tend to preclude extensive travel to engage in fishing and the lack of local opportunity, especially in the Merrimack. A clean Merrimack with an established shad fishery would undoubtedly prove a powerful attraction to the nearby population, including both licensed fishermen and younger people permitted to fish without a license.

The value of the restored shad fishery in the Merrimack River can be estimated by various measures. Massachusetts experience suggests that the catch ratio of males to females is about three to two. Assuming an average weight per mature male shad of three pounds and per female at 5 pounds, the total catch by anglers would amount to about 760,000 pounds. In recent years commercial shad landings in Connecticut have had a wholesale value of from 27 to 32 cents a pound. (Fish. Stat.) This would yield a value for the Merrimack fishery of something like $205,000 to $243,000 a year.

However, as with salmon, the wholesale price is probably an inadequate measure of the value of the shad fishery. A 1969 study by the Corps of Engineers assumed a value of $5.00 per day for expenditures by shad fishermen and an average catch of one fish per day, yielding a total value for the fishery of about $1,000,000. (Preliminary Summary) Translated into 1974 dollars this would represent a value of about $1,357,000.

If one accepted the 1970 United States average freshwater fishing expenditure per day, adjusted for inflation, of $8.07, the total value of the sport fishery would become $1,614,000.

However, it is not certain that actual expenditures would be this high. Costs of fishing equipment and bait would be low. There would be some expenditure for hire or maintenance of boats, since the chances of success from a boat are about twice as great as from bankside fishing. Still, many fishermen would try their luck from the banks. Most fishermen would probably be from the immediate area, within anything from walking distance to a few hours travel. Accordingly, they would not need to make large expenditures for food, drink, lodging, rental of cars, and the like. It seems quite probable, therefore, considering the nature of the basic fishery and of the nearby population, that the monetary value of a fishing day is not a proper measure for this fishery.

Let us consider another possibility. The depressed state of the regional economy could make shad fishing attractive as an inexpensive means of supplementing the diet. If this were to be the case, a reasonable measure of value would be the retail cost of the equivalent amount of shad at the fish market. Whole shad cost about $1.10 a pound for males and about $1.80 a pound for females with roe. (Sanborn) Assuming the same catch proportions as before, the retail value as food to the shad fishermen would be $396,000 for males and $720,000 for females or a total of about $1,116,000. If one added to this nominal average daily expenditures of perhaps $1.00 per day for all costs, the value of the fishery would become about $1,300,000.

In view of current developments in costs of food, especially meat and fish, the actual value of shad to anglers could be higher than estimated here. Similarly, rising costs of automobile transportation, as reflected in the price of both vehicle and fuel, could add to costs of those engaging in the fishery even from quite nearby. Accordingly, the value derived immediately above for the shad fishery appears to be conservative rather than extravagant. At any rate the shad fishery appears clearly to have a value in excess of $1,000,000 a year by any reasonable measure. A value of $1,300,000 (in 1974 dollars) seems quite likely.

Thus, the total potential value of the salmon and shad fishery on the Merrimack would appear to lie in a range between about $1,900,000 and $2,200,000 per year. It could be as low as $1,250,000 and as high as $3,000,000, depending upon assumptions about the value of fishing activity and the size of the salmon catch. Most of the benefit from the shad fishery would redound to the local economy, while probably about half of the benefits from the salmon fishery would be realized in the immediate region.

5.0 BASE FLOW DETERMINATIONS

5.1 Anadromous Fish Requirements

The ultimate purpose of the water quality section of the Merrimack diversion study was to determine which existing water quality parameters have an impact on proposed anadromous fish restoration. This fish restoration was considered in light of proposed discharge diversion rates. Data on a total of 37 major water quality constituents, 26 minor constituents, and 22 pesticides/herbicides were collected and graphically and statistically analyzed. The analysis was directed toward determining monthly water quality characteristics in the three reaches of the Merrimack under the most recent conditions. During the diversion study, an extensive literature search of published water quality requirements of fisheries was conducted. Results of the search are found in Table 5.0. Based upon these requirements, maximum water quality limits were suggested for a total of 29 parameters. Limits were not suggested for all 85 parameters investigated because published data is not available on all parameters. However after considering maximum water quality limits suggested in Table 5.0, only four parameters examined during the last six data years posed any problem to anadromous fish restoration.

The first two of these parameters, copper and nitrogen-ammonia, exceeded recommended limits on a small number of occasions during the six year study period. For both of these parameters, data were lacking. In the case of copper, only composite sample averages were available.

Water temperature was also at or above the maximum suggested limit during the summer weeks. However, as discussed earlier, water temperatures in the study reaches of the Merrimack River are controlled primarily by seasonal air temperature fluctuations. July and August are the months when high water temperatures pose the greatest potential hazard because of the seasonal high air temperatures. Although it was clear that air temperature controlled water temperature to a great extent, it was not clear whether dams on the Merrimack (and their resultant discharge impoundment) influenced overall water temperature. To determine this, plots of discharge during summer months (June - September) versus water temperature during the period of 1969-1972 were constructed at both Reach 1 and 3. The water temperature data plotted for Reach 1 (Figure 18) was obtained at Water Quality Station 2 which is located in the gatehouse of the Pawtucket Dam. Consequently, these data are indicative of water temperatures in the dam pool. Water temperature data plotted for

TABLE 5.0 *

Water Quality Requirements of Anadromous
and Fresh Water Fisheries

Parameter	Suggested Max. Limit	Published Criteria
Barium**	5mg/l	(1) for the protection of fish and aquatic life 5mg/l is considered to be maximum concentration to be allowed (2) barium is a heavy metal; the combined concentration of heavy metals should not exceed 1mg/l
Cadmium	.01mg/l	(1) lethal concentrations for fish varies from about .01 to about 10mg/l depending on the test animal, type of water, temperature, and time of exposure (2) cadmium acts synergistically with other substances to increase toxicity. Cadmium in concentrations of .03mg/l in combination with .15mg/l of zinc cause mortality of salmon fry
Calcium	52mg/l	(1) presence of Ca^{++} reduces toxicity of several other compounds, i.e., Pb, Al, Zn (2) calcium chloride & nitrate are toxic to fish at 300-1000mg/l as Ca (3) fish survive 1-3 days in waters with $CaCl_2$ at 2500-4000mg/l as Ca (4) 95% of waters with good mixed fish fauna have less than 52mg/l
Carbon dioxide	25mg/l	(1) concentrations not exceeding 25mg/l are recommended by the National Technical Advisory Committee (DeCola, 1970) (2) should not exceed 25mg/l, because higher concentrations cause an increase in dissolved oxygen requirements of salmonoids (DeCola, 1970)

TABLE 5.0 (continued)

Parameter	Suggested Max. Limit	Published Criteria
Carbonate		Not detrimental to fish life, but their buffering action and effect upon PH may contribute to the toxicity of high PH values
Chloride	170mg/l	(1) 400mg/l is harmful to trout (2) 95% of waters with good fish fauna have less than 170mg/l
Chromium**	1mg/l	(1) for protection of fish concentration should not exceed 1mg/l (2) it is a heavy metal
Cobalt	1mg/l	(1) 1mg/l was not harmful to carp, rainbow trout, and char (2) 10mg/l is the lethal concentration for sticklebacks
Copper**	0.007mg/l during migration of salmon	(1) 0.048ppm at 20mg/l $CaCO_3$ is the incipient lethal level for adults (BCL, 1971) (2) 0.007 is maximum safe level for salmon migration (Battelle Columbus Lab., 1971) (3) 0.032mg/l is incipient lethal level for juvenile salmon (DeCola, 1970). Salmon parr avoid 0.0025ppm (BCL, 1971) (4) lethal level is half the above concentration in the presence of Zn
Dissolved oxygen	5-6mg/l (seasonal)	(1) 5ppm needed for successful spawning of shad (Walburg, 1960b) (2) 6ppm required for migration of salmon
Dissolved solids	400mg/l	(1) 95% of waters with good fish fauna have less than 400mg/l (2) limiting concentration of dissolved solids for fresh water fish are not definitely known; may range 5,000-10,000mg/l

TABLE 5.0 (continued)

Parameter	Suggested Max. Limit	Published Criteria
Fluorine	1.5mg/l	(1) 1.5mg/l causes slower and poorer egg hatching (2) 2.3-7.3 is TLm for trout at 18°C in soft water (3) 1.5mg/l is recommended as concentration which will not interfere with aquatic life
Hardness	20ppm	(1) hard water reduces the toxicity of various metals (2) Atlantic salmon are typically found in very soft waters with total hardness less than 20ppm
Iron	0.7mg/l	(1) 95% of waters that support good fish fauna have less than 0.7mg/l (2) 0.2mg/l is lethal threshold concentration for 3 species of fish (3) low PH values increase toxicity
Lead**	0.1mg/l	(1) lead more toxic in soft water (2) toxicity increases with low D.O. (3) 0.1mg/l recommended by W.Q.C.
Magnesium	14mg/l	(1) 95% of waters with good fish fauna have less than 14mg/l (2) 300mg/l is reported as toxic to sticklebacks (3) $MgCl_2$ and $Mg(NO_3)_2$ is toxic at 100-400mg/l as magnesium
Manganese	1mg/l	(1) 15mg/l has been tolerated by tench, carp and trout for 7 days (2) 1.0mg/l is recommended as concentration which will not affect fish and aquatic life (3) 40mg/l is lethal concentration for sticklebacks

TABLE 5.0 (continued)

Parameter	Suggested Max. Limit	Published Criteria
Mercury**	0.004mg/l	(1) 0.004 to .02mg/l have been reported as harmful to fresh water fish (2) 0.008 is lethal concentration limit for sticklebacks (3) 0.05-0.1mg/l fish were killed in 6-12 days
N-Ammonia	0.5mg/l	(1) 15-60mg/l of CO_2 reduces toxicity (2) low D.O. increases toxicity (3) low PH decreases toxicity (4) concentration of 1.5mg/l is not harmful to most varieties of fish (5) 0.7mg/l was lethal to trout exposed 390 minutes
N-Nitrate	4.5mg/l	(1) 95% of waters supporting good fish life have less than 4.5mg/l (2) principal effect of nitrates is to stimulate growth of plants (3) the toxic threshold concentration, as sodium nitrate, for the flatworm *Polycelis nigra* is reported to be 2670mg/l
N-Nitrite	30mg/l	Concentration of 50mg/l $NaNO_2$ is fatal to minnows after exposure of 14 days
N-Total	10mg/l	For most beneficial uses the total concentration of nitrogen compounds should not exceed 10mg/l
pH	6.5-8.5mg/l	(1) salmon found typically in waters of 5-7 (DeCola, 1970) (2) fish typically found in waters 6.5-8.5 (DeCola, 1970)
Phenols	0.3mg/l	(1) threshold for disturbance in trout is 1.3mg/l (2) other studies on threshold ranges for fish are between 0.28-3.0mg/l

TABLE 5.0 (continued)

Parameter	Suggested Max. Limit	Published Criteria
		(3) 1.0mg/l should be considered threshold concentration for fish (4) .2mg/l will not hurt fish (5) low D.O. increases toxicity (6) 0.28 found to kill fish in a river
Phosphate		(1) 24 hour exposure to 545mg/l was not toxic to rainbow trout fingerlings (2) 24 hour exposure to 1090mg/l is toxic to trout fingerlings (3) generally not considered toxic to fish
Potassium	50mg/l	(1) 50-200mg/l is toxic to fish when KCl and KNO_3 is tested in soft or distilled water (2) about 400mg/l is toxic to fish when KCl, KNO_3, K_2SO_4 is tested in various kinds of water (3) 50mg/l of K is toxic to sticklebacks
Silica		Should not be harmful to fish, because Si is taken from water and used in the synthesis of diatom tests
Silver**	1.0mg/l	1.0mg/l is recommended for protection of fish and aquatic life
Sodium	85mg/l	(1) 95% of U.S. waters supporting good populations of fresh water fish have less than 85mg/l Na and K combined (2) 500mg/l is lethal to sticklebacks
Sulfate	90mg/l	95% of U.S. waters with good fish fauna have less than 90mg/l

TABLE 5.0 (continued)

Parameter	Suggested Max. Limit	Published Criteria
Temperature	variable	(1) 20°C contributes to mortality of Atlantic salmon (DeCola, 1970) (2) 23°C prevents movement of adult salmon into fresh water (DeCola, 1970) (3) Edsall (1970) noted minimum survival of alewife larvae at 27.8°C
Zinc**	0.09mg/l	(1) 0.60ppm is the incipient lethal level for <u>Salmo salar</u> at 20ppm $CaCO_3$ (2) 0.09 is the avoidance threshold for migrating salmon at 20ppm hardness (3) levels are half of the above concentrations in the presence of Cu

* McKee and Wolf, 1963. Water Quality Criteria (unless otherwise referenced).

** Indicates that substance is a heavy metal. The total concentration of heavy metals should not exceed 1.0mg/l.

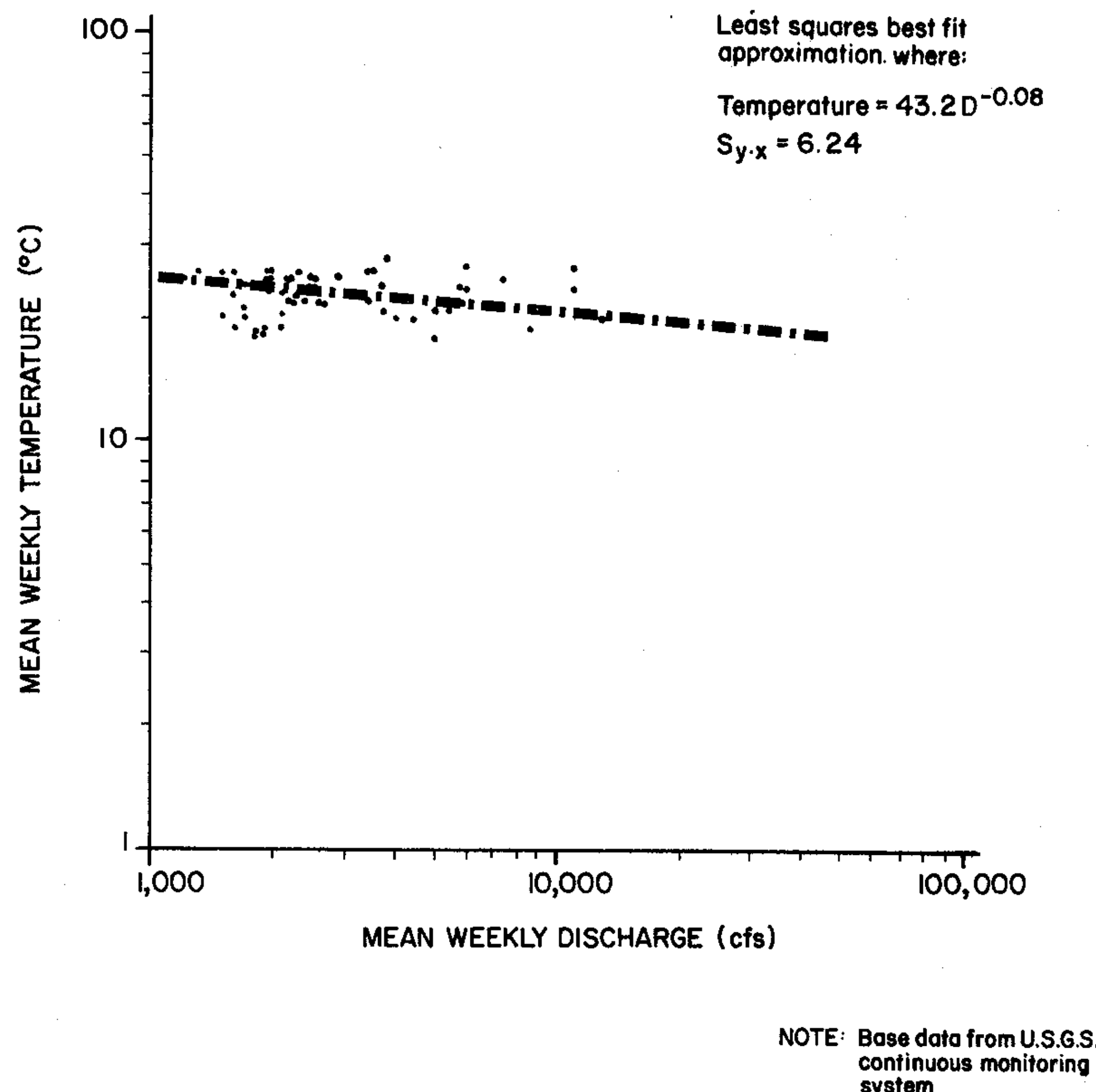


Figure 18

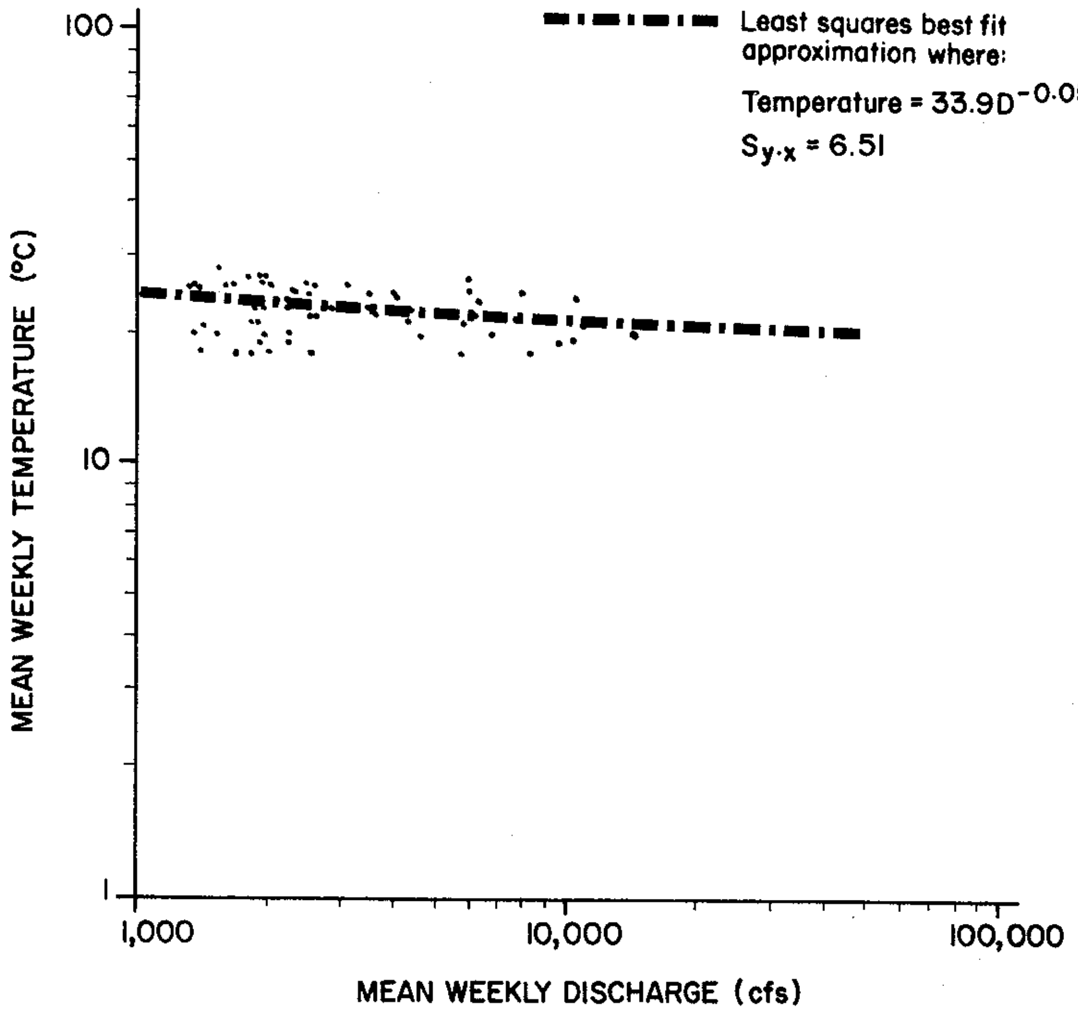
Discharge vs. Water Temperature
June – September 1969 – 1972
Reach 1 – Water Quality Station 2

Merrimack River Diversion Study

Reach 3 (Figure 19) were obtained at Water Quality Station 4 which is located in open, unobstructed water. In both cases, water temperature was not directly related to discharge, obstructed or unobstructed, and water temperatures were in the range of 18-28°C. The regressions performed on these data indicate that a 10-fold change in flow would make at most a 20% change in temperature. (See Figures 18 and 19).

The final water quality parameter to be considered which exceeded recommended tolerance limits is dissolved oxygen (DO). As discussed earlier, DO concentration is controlled ultimately by seasonal air temperature fluctuations. These in turn control water temperature, biological processes, chemical activity, and other physico-chemical parameters which substantially affect DO. Furthermore, dissolved oxygen concentrations (mean weekly) vary from reach to reach. An example of this variance is illustrated in Figure 20, which shows the mean weekly DO during 1969 at Reaches 1 and 3. Of particular significance is the DO in Reach 3 during summer and fall months which is generally lower than the DO in Reach 1. This is of concern when DO levels are below 6 mg/l. Below 6 mg/l even the small difference in mean weekly DO is significant in terms of anadromous fisheries. During the 6-years for which data were evaluated, dissolved oxygen concentrations were generally lower in Reach 3 than Reach 1. Data on Reach 2 DO were not obtained through continuous daily monitoring (as in Reaches 1 and 3); however, limited data suggest that DO in Reach 2 is higher than in Reach 3. During the examination of discharge-related parameters, plots of flow versus mean weekly DO concentration were prepared for Reaches 1 and 3. (See Figure 21 and 22). The data were divided into summer (June through September) and winter (October through May) to isolate the summer observations of low flow and low DO. The scatter of the plots indicates that no simple relationship exists between DO and discharge. As pointed out earlier, DO is strongly temperature dependent. According to Hem (1970), there is an inverse relationship between DO and temperature. For example, below is a list showing the solubility of oxygen in fresh water exposed to water-saturated air (total pressure 760 mm) at various temperatures:

Temp., °C	DO, mg/l
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2



NOTE: Base data from U.S.G.S. continuous monitoring system

Figure 19
Discharge vs. Water Temperature June – September 1969 – 1972
Reach 3 – Water Quality Station 4

Merrimack River Diversion Study

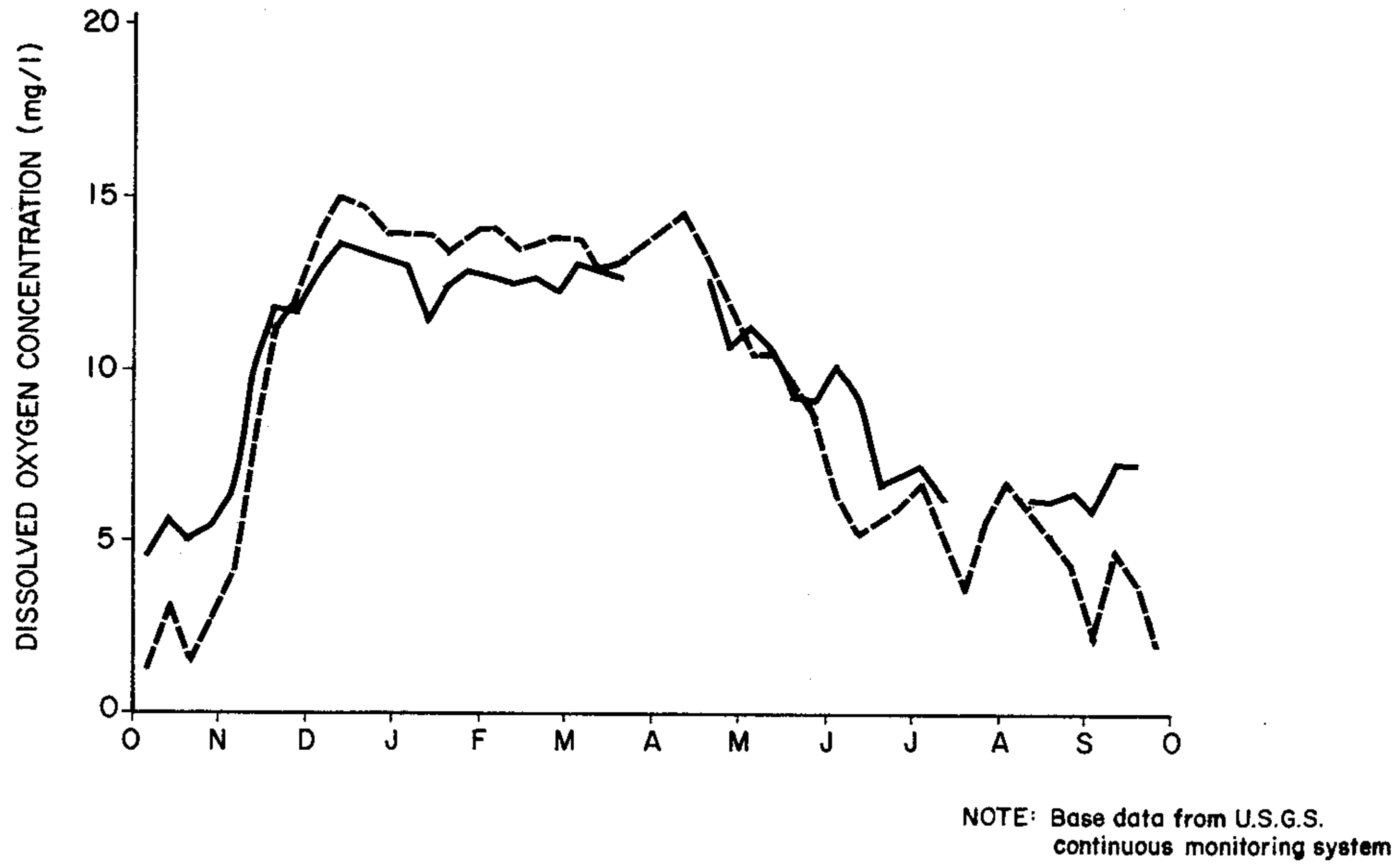


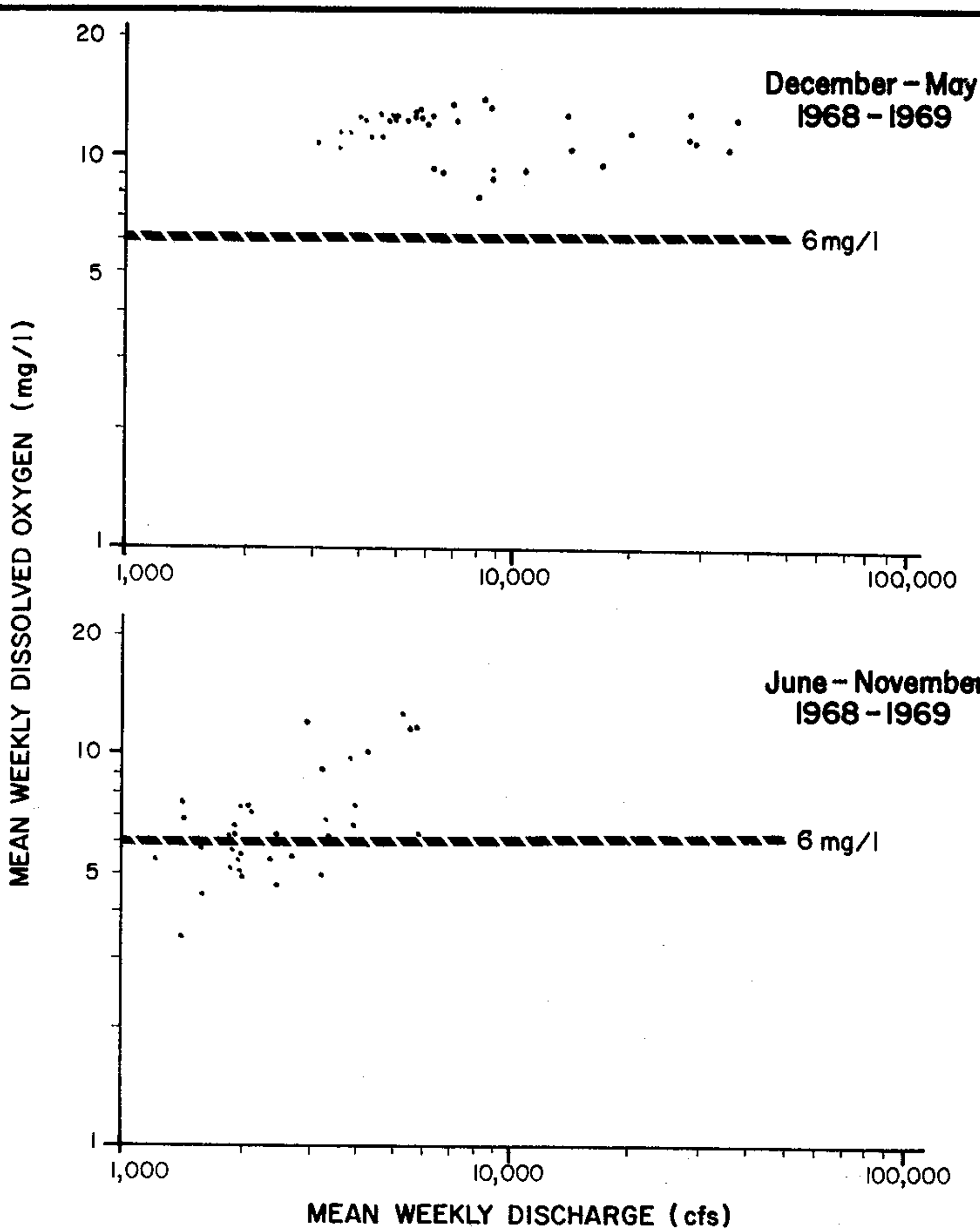
Figure 20

Comparison of 1969 Mean Weekly Dissolved Oxygen Reach 1 and Reach 3

Merrimack River Diversion Study

—— Reach 1

- - - - Reach 3



NOTE: Base data from U.S.G.S. continuous monitoring system

Figure 21

Desirable level for fish

Discharge vs. Dissolved Oxygen
Reach 1 Water Quality Station 2

Merrimack River Diversion Study

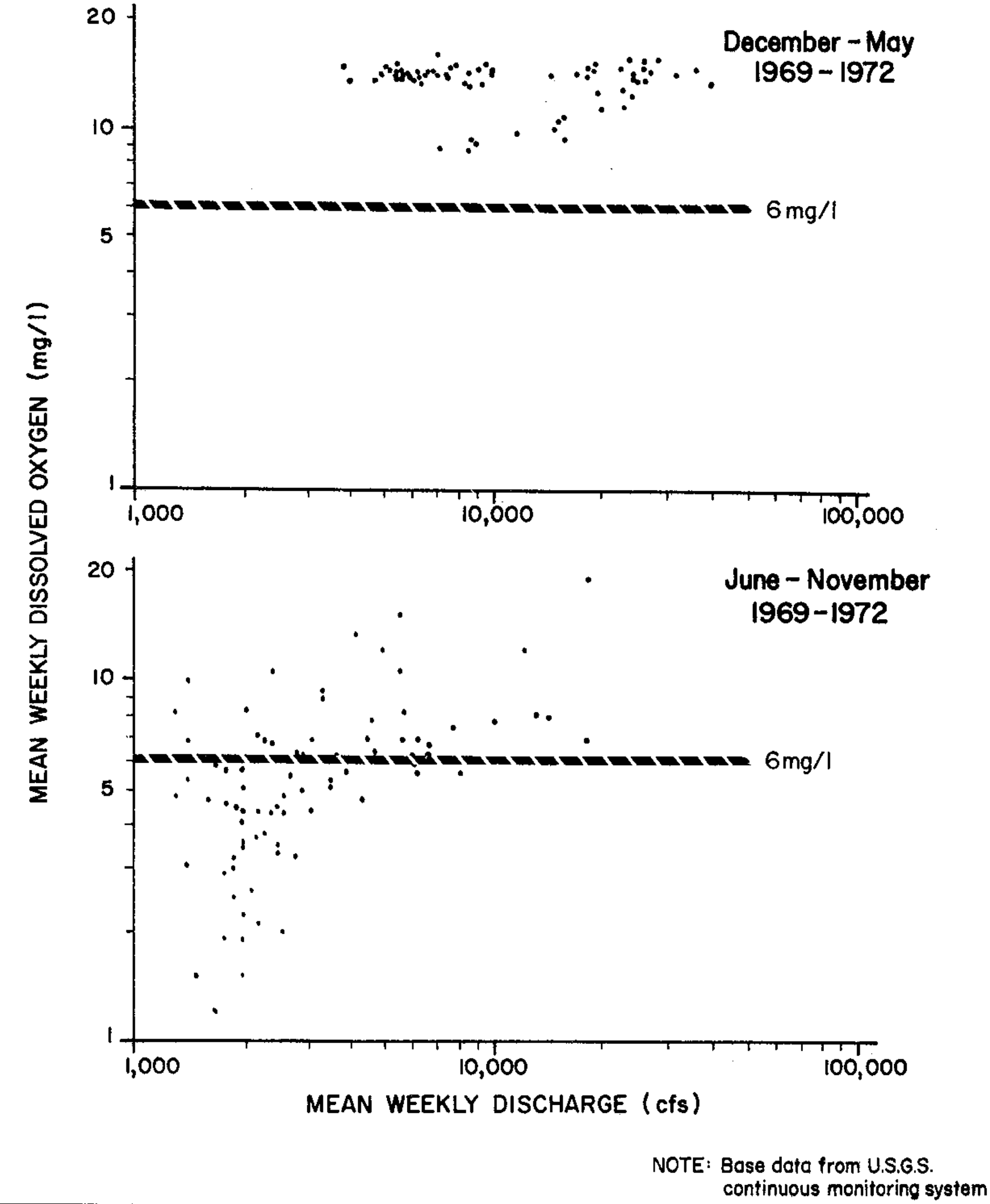


Figure 22

Desirable level for fish

Discharge vs. Dissolved Oxygen
Reach 3 Water Quality Station 4

Merrimack River Diversion Study

As temperature increases, DO decreases. The dissolved solids content of water is also inversely related to the DO content. However, the dissolved solids content is highly variable during any given time increment. Hence, over a long term, its impact on DO is minor. Water temperature on the other hand is controlled by seasonal air temperature fluctuations. Because seasonally-controlled water temperature changes occur gradually, DO changes occur over a long term and these changes are major. Of course short-termed, localized changes in DO are common where wastewater or pollutants are added or where intense biochemical activity occurs.

Two observations of importance can be made from these Figures, however. First, in no case is the winter DO below 6.0 mg/l in either reach. Second, flows above 3,500 cfs are very rarely associated with DO less than 6.0 mg/l (5 such observations in Reach 3, none in Reach 1). In any event, maintenance of a DO level of 6.0 ppm is to be expected when river flow exceeds 3,500 cfs. It should be noted however, that DO stratification is expected to occur behind dams on the Merrimack. Such stratification results in localized zones on high, low, and average DO concentrations.

Other flow conditions of importance to anadromous fish restoration are (1) maintenance of freshets during March and April (to insure attraction of migrants to the mouth of the estuary), (2) maintenance of flow velocities of 1-2 feet per second during March through October for rheotaxic response, and (3) maintenance of water depths of 3-30 feet during April for shad reproduction.

Earlier studies (Normandeau, 1971) have indicated that estuary stratification occurs at about 3,000 cfs and that full freshet conditions occur at about 6,000 cfs. Examination of the stage-discharge curves (Figures 4 and 5 and Appendix A) indicates that flow velocities will exceed 2 feet per second at most cross-sections, even at flows as low as 3,000 cfs. Additionally, even zero flow leaves more than 3 feet of water at all cross-sections.

5.2 Fishway Requirements

Preliminary design of the proposed fishways at the Essex and Pawtucket Dams is underway. These fishways are being designed to operate on a flow of 94 cubic feet per second and the top elevations of the fishways will correspond approximately to the top elevations of the dams. In addition to the 94 cfs for actual operation of the fishways, about 350 cfs will be required as an attraction flow.

Thus, since 3,500 cfs is generally required by the canals at both dams (See Section 3.1.3), total river flow should be nearly 4,000 cfs to insure proper operation of fishways during the up-migration period of March, April, May, and June. (Dalley, 1975)

It should be noted that the average flow in the Merrimack is low enough (below 3,500 cfs) to eliminate flow over the dams during the months of July, August, September, and October. (See Section 3.2)

Current fishways planning calls for routing late summer, down-migrating fishes through the canal systems adjacent to the dams and using an inactive penstock or a specially constructed channel to return the fish to the mainstem below the dams. Thus, fishway flows need not be maintained during these months. Table 5.1 summarizes month by month flow requirements for anadromous fisheries.

5.3 Resource Requirements

5.3.1 Water Supply

Reference to Table 3.4, "Present and Projected Water Withdrawal from Merrimack River", indicates the future discharge requirements for various points along the River. These are:

Lowell Municipal Water Supply:	1990 needs 28 cfs 2020 needs 35 cfs
Lawrence & Methuen Municipal Water Supply:	1990 needs 32 cfs 2020 needs 40 cfs
Andover, MA:	1990 needs 17 cfs 2020 needs 28 cfs
Haverhill, MA:	by 2008, 7 cfs
New Hampshire needs:	by 2020, 440 cfs

These represent the major consumptive uses of the Merrimack. The total need is on the order of 77 cfs by 1990. This should in no way compromise any anadromous fish restoration program. 2020 needs may total 540 cfs, but returns from advanced wastewater treatment will offset this considerably.

TABLE 5.1

Month by month summary of anadromous fisheries requirements, Merrimack River Diversion Study area.

Month	DO (mg/l)	Temp. (°C) Max.	Flow Requirements
Jan.	-	-	-
Feb.	-	-	-
Mar.	6	20 (salmon)	6000 cfs to insure freshet for homing
Apr.	6	14 (shad)	Same
May	6	14 (shad)	3500 cfs to insure sufficient dissolved oxygen (3000 cfs will insure rheotaxic and shad spawning)
Jun.	6	14 (shad)	Same
Jul.	6	22 (shad)	Same
Aug.	6	25	Same
Sept.	6	25	Same
Oct.	6	25	Same
Nov.	-	-	-
Dec.	-	-	-

Note: Flow requirements listed are the most stringent for anadromous fish, but do not necessarily meet fishway or other resource requirements.

The major non-consumptive users are the Pawtucket and Essex Dams. Each of these currently requires 3,500 cfs for their power generation and neither are anticipating future expansions (Dalley, 1975). Since these waters are returned to the river, they influence flow requirements only for fishways, as presented above in Section 5.2.

It should be noted that diversions during flood stages may actually provide positive benefits to the power generating facilities in the Lowell and Lawrence canals. During these times, the river stage is high enough to back up into the penstocks of the generating facilities, reducing their output capacity. Reduction of flood stage could mitigate this problem.

5.3.2 Wetlands

Since the wetlands near the river do not depend on river flow to sustain their water regiman, no flow requirements should be set for these areas. (See Section 3.4.1)

5.3.3 Navigation

As was noted in Section 3.4.3, sediment deposition occurs generally throughout the river during low flow periods, while it is either localized at Joppa Flats or flushed out of the river during periods of higher flow. (Normandeau, 1971) Thus, low flow occurrences could lead to impedance of recreational boat traffic, were they to occur over extended periods. No figures are currently available to define at what discharge level sediment will be scoured from navigation channels. Instead, it may be assumed that, so long as the spring freshet discharges are not significantly lowered, the channels will experience an annual flushing of sediment and remain passable to small craft.

5.3.4 Riverside Land Use

While recreational, residential, and industrial uses may be expected to intensify along the river, none which would suffer from diversion activities have been identified. The proposed Urban Cultural Park in Lowell will require less flow than the power generating facilities which the canals supply, and tentatively planned State Park in West Newbury will be placed along tidal waters. Thus, diversion will affect neither of the potential most intensively used riverside recreation areas.

5.3.5 Flooding

Potentially positive effects of diversion during flood stages were discussed in Section 3.4. This effect, however, is almost immeasurably small, since the maximum potential diversion volume (2,000 cfs) is only 1 1/2% of the 100-year flood flow of 135,000 cfs. In addition, there may be a slight positive impact of floodwater diversion on flood insurance rates for areas downstream of the diversion. Under the Federal Flood Insurance Program, actuarial rates are based on the 100 - year flood stage. If the diversion program can be shown to reduce the level of this flood stage, flood insurance rates may be lowered correspondingly. Flood stages however, are not expected to be reduced substantially by a diversion which is 2,000 cubic feet per second.

6.0 DIVERSION STUDIES

The previous sections of this report have provided the data base for an assessment of the influences of various possible rates of water diversion on the potential anadromous fisheries and other riverine resources of the Merrimack. It is the purpose of this section to assess those effects. Diversion rates which will be examined are:

100 cfs
300 cfs
500 cfs
800 cfs
1,100 cfs
1,500 cfs
2,000 cfs

At present, there are no exact locations for the diversion works. Studies by Hayden, Harding & Buchanan, however, have indicated that the most likely and suitable locations are above the Pawtucket Dam in Lowell. Two suitable areas for a diversion are: (1) just above the dam (near the site of the existing Lowell water supply diversion); and (2) farther upstream in Tyngsborough. Both of these potential sites are located in study Reach 1. Therefore, primary emphasis will be given to that reach in the discussions which follow.

Finally, it should be noted that there are no firm designs for an intake structure. Thus, part of the purpose here will be to discuss the influences of various possible designs of the intake. This will take the form of a general description of desirable and undesirable characteristics which can then be used to guide actual intake design.

6.1 Control Flows

As demonstrated in Section 5, required flows in the Merrimack may be set on a number of different criteria. In virtually all cases, the most stringent requirements are those which will meet the needs of the various anadromous fish. In this section, water quality data, discharge data, and locations of critical cross-sections are compared with anadromous fish requirements to arrive at monthly control flows and to predict the effects of various diversions on these flows. The control flows are those flows which must be maintained in the Merrimack to insure the survival of an anadromous fishery, once established.

6.1.1 Anadromous Fish Requirements

Examination of the requirements and tolerances of all seven species made it evident that the species having the lowest tolerances and most stringent requirements are the Atlantic Salmon and the American Shad. If the conditions for successful restoration of these two species are met, then it should also be possible to establish runs of alewife and blueback herring in the Merrimack. Other anadromous species present in the past might also return. 24 parameters that might adversely effect fish life were compared to average levels in the river. (See Appendix C and Section 3) All except copper, ammonia, dissolved oxygen, and temperature are well below the tolerance limits of salmon and shad. Comparisons of discharge with copper and ammonia concentrations failed to show a correlation between flow rate and constituent levels. Although water temperature can be an important limiting factor during summer and early fall, the data show that it is primarily related to ambient air temperature and not discharge. The remaining significant parameter, dissolved oxygen, is discharge related and therefore constitutes one of the major considerations in setting control flows. Examination of the seven river cross sections revealed that two areas are critical in terms of anadromous fish restoration requirements; one is the Pawtucket Dam, and the other is the Lawrence Dam. At these two locations ponding occurs behind the dams, and when river discharge is less than 3,500 feet there is no flow over the rapids beneath the dams. As discussed in Section 5.2, this may present problems for down-migrants. Fishway designs, however, are such that bypass routes will be provided during these times. At other times of the year, and at the other 5 cross sections examined, the minimum flows shown in the succeeding pages would fulfill the physical needs of migrating anadromous fish. The only possible exception to this generalization is behind the Pawtucket and Essex Dams. As pointed out earlier, DO stratification may occur in the dam pools behind the dams. Consequently zones of low DO may be present, particularly at depth. Anadromous fish, however, are known to move along the tops and edges of stratified zones in order to obtain the maximum oxygen available.

During the months when anadromous species are migrating upriver and while spawning is occurring in the river, it is of major importance that there be sufficient flow to guarantee that levels of dissolved oxygen do not fall below 6 mg/l. As shown in Section 5.1, this is virtually assured during the summer months (June through September) if flows are above 3,500 cfs. Throughout the remainder of the year, levels of dissolved oxygen will be above 6 mg/l, regardless of flow rate, and will be sufficient both for anadromous fish and for the resident macroinvertebrates which serve as a source of food when the fish are resident in the river. In fact, the majority of the macroinvertebrate species that occur in the segment of the river that flows through Massachusetts are forms classified as pollution tolerant, although in some locations intermediately tolerant species are found (USDI, 1966). Such species are adapted to living in waters having dissolved oxygen concentrations on the order of 3 to 4 ppm.

For some anadromous species, salmon in particular, the occurrence of freshets is required to initiate the run upriver. A freshet is defined as a great rise or overflowing of a stream caused by heavy rains or melted snow. A control flow volume of 6,000 cfs during March and April is the discharge at which stratification in the estuary will occur, and at which a plume of fresh water will extend beyond the mouth of the river. In the Merrimack, springtime is the critical period for this requirement since water temperatures after June exceed tolerance thresholds for migrating salmon. In order to ensure the occurrence of freshets during spring it is essential that "peak chopping" does not take place to alter natural variability in discharge. Because most anadromous species exhibit rheotaxis, a flow rate of 1 - 2 feet per second during upriver and downriver migration periods is required. For the shad, which would spawn in the river, water depth of 3 - 30 feet over suitable substrate is a requirement for successful reproduction. Finally, there must be sufficient discharge to operate fishways at the two dams and other major obstructions during periods when spawning adults are moving upriver and to provide sufficient flow for the spent adults and young moving down.

6.1.2 Required Flows

The following control flows for each month are based on the physical and chemical conditions that must be fulfilled in order to restore anadromous fish to the Merrimack River successfully. These flows were determined to be biological minima which are necessary to insure marginal survival of anadromous fish. Based upon flow records for the Merrimack, diversions in excess of 2,000 cfs would be possible at various times of the year. However, because of the stringent biological needs of anadromous fish, the maximum allowable diversion will be limited to 2,000 cfs.

Month	Required Flow
January	2,000 cfs This is near the ten year low flow and according to Hynes (1970) sufficient dissolved oxygen will be present at this discharge volume to ensure the survival of most macroinvertebrate forms.
February	2,000 cfs Same as for January
March	6,000 cfs This discharge will produce a freshwater plume outside the mouth of the Merrimack. These "freshet" requirements are larger than any other requirement.
April	6,000 cfs Same as for March
May	4,000 cfs This discharge rate will provide: 1) Sufficient dissolved oxygen for upriver migrating salmon, shad, alewives, and bluebacked herring. 2) The dissolved oxygen required by shad spawning in the river. 3) Sufficient water to operate fishways. 4) Peaks that will produce freshets of sufficient size for these months to initiate anadromous fish runs. 5) Sufficient flow to ensure continuous progress of upriver migrants.
June	4,000 cfs Same as for May
July	3,500 cfs At this discharge rate there will be sufficient levels of dissolved oxygen to fulfill the requirements of downriver migrating young and spent adults of salmon, shad, alewives, and blueback herring.

August	3,500 cfs	
	Same as for July	
September	3,500 cfs	
	Same as for July	
Ocotober	3,500 cfs	
	Same as for July	
November	3,500 cfs	
	Same as for July	
December	2,000 cfs	
	Same as for January	

6.2 Restoration Potential and Diversion Effects-Average Year

The required flows developed above may be used to assess both the potential for restoration of anadromous fish to the Merrimack and the influences of the proposed diversions on the restored fishery. Restoration potential may be estimated by comparing required flows to existing average flow conditions in the Merrimack. The effects of each of the suggested diversion rates on the anadromous fish restoration program are assessed by comparing the required flows for each month with the depressed discharge volume following removal of water.

Table 6.0 presents the information for these two comparisons. The required flows are those developed above. For existing discharge volumes, the mean seven-day average flow, the mean seven-day minimum flow, and the mean seven-day maximum flow are used to represent an average year.

Restoration Potential

A comparison of required flow and average flows in Table 6.0 indicates that, with certain qualifications, restoration of anadromous fish to the Merrimack should prove possible. From January until June and during November and December, average

TABLE 6.0

AVERAGE FLOWS, MERRIMACK RIVER

	Required Flow, cfs	Average Flow, cfs	Average Minimum, cfs	Average Maximum, cfs
January	2,000	5,000	3,400	9,000
February	2,000	6,200	4,200	8,600
March	6,000	10,400	7,000	17,000
April	6,000	17,000	11,800	25,000
May	4,000	9,600	6,600	14,400
June	4,000	5,000	3,000	8,000
July	3,500	3,000	1,800	3,600
August	3,500	2,400	1,200	2,800
September	3,500	2,200	1,200	3,000
October	3,500	3,000	1,600	4,600
November	3,500	4,800	3,000	5,200
December	2,000	5,400	3,200	7,400

flows in the Merrimack are more than sufficient for the requirements of anadromous fisheries. Flows during late summer and early fall months (July through October), on the other hand, are often below the required flow levels. These low flows may lead to low dissolved oxygen immediately behind the dams, perhaps causing mortality to a portion of the river's shad eggs and juvenile shad. Additionally, temperature levels during these months are often at or above the 22°-25°C requirements for shad and Atlantic Salmon. Thus, as discussed in Section 4.2, late summer migrations are not likely in the Merrimack. This, however, was most probably the case historically as well. The indication is that a spring migrating race of salmon inhabited the Merrimack. This may well increase the number of years required to establish the fishery, but should not prevent success in the program.

Diversion Effects

Comparisons of required flow and average flows (Table 6.0) reduced by various potential diversion rates indicates the potential effect of the various rates on anadromous fisheries.

January:

Diversion rates between 100 and 1,100 cfs will not reduce flow below required levels.

Diversion rates of 1,500 and 2,000 cfs will violate flow requirements only during low flow conditions.

February, March, April and May:

All diversion rates studied (100-2,000 cfs) may be achieved without reduction of flow below required levels, even during the low flow weeks, except for March, when only 1,000 cfs may be diverted during low flow.

June:

Up to 1,000 cfs could be diverted under average conditions during June. 2,000 cfs could be diverted under high flow conditions. Under low flow conditions, no diversion would be possible.

July, August, September and October:

During these four months, no diversions could be allowed under low flow or average conditions. In weeks of high flow, diversions of 100 cfs during July and 1,100 cfs during October could be sustained.

November:

Diversion rates of up to 1,300 cfs could be allowed under average conditions. Up to 1,700 cfs could be withdrawn under high flow conditions. Low flow conditions would preclude diversion.

December:

Under both high flow and average conditions, diversion rates up to the maximum of 2,000 cfs would be possible. Low flow conditions would restrict withdrawals to 1,200 cfs.

In summary, diversions up to the 2,000 cfs limit could be accomplished under average flow conditions during January through May and December without violating anadromous fish flow requirements. Diversions would have to be restricted to 1,000 cfs in June and 1,300 cfs in November to avoid impacting upon flow requirements. During July through October, existing marginal conditions preclude any diversion. With these late summer restrictions, the diversion of substantial volumes of water from the Merrimack is not inconsistent with the establishment of a restored anadromous fishery.

6.3 Restoration Potential and Diversion Effects - Extreme Year

One of the most significant problems facing the restoration of anadromous fisheries in the Merrimack River is the possible occurrence of extreme low flow years leading to a partial or complete migration or spawning failure.

Two approaches were taken in assessing this possibility. The first was to compare anadromous fish flow requirements to a hypothetical dry year consisting of 10-year low average flows during each month. The second was to compare required flows to flows observed during historical droughts.

Table 6.1 presents the data for these comparisons. The 10-year low average is taken from the flow-duration summary in Section 3.2. Recent historical droughts in New England were observed in 1941, 1957, and 1964 through 1966. Examination of the Merrimack flow records (Appendix B) indicated that the prolonged 1964-1966 drought yielded the lowest average monthly flows in the Merrimack and these years were selected for analysis.

TABLE 6.1

EXTREME LOW FLOWS, MERRIMACK RIVER

	Required Flow, cfs	10-Year Low Average Flow,cfs	1964 Flow,cfs	1965 Flow,cfs	1966 Flow,cfs
January	2,000	3,200	8,200	2,400	2,600
February	2,000	4,000	6,700	3,800	4,800
March	6,000	5,200	13,700	5,900	11,600
April	6,000	9,400	16,800	8,800	9,100
May	4,000	4,800	5,600	4,100	7,700
June	4,000	2,600	1,700	2,200	3,600
July	3,500	1,600	1,400	1,100	1,200
August	3,500	1,400	1,200	900	1,400
September	3,500	1,400	1,000	1,400	1,900
October	3,500	1,400	1,100	2,200	3,300
November	3,500	2,800	2,000	2,800	6,900
December	2,000	3,400	2,500	2,400	4,600

Restoration Potential

As can be seen on Table 6.1 years of extreme low flow could seriously stress an anadromous fishery in the Merrimack River.

In fact, during the hypothetical low flow year (and during 1965), required flows would only be met during January, February, April, May, and December. March would be a marginal month and the period from June to November would offer serious problems.

Since the major migratory period is expected during April, May, and June, it is likely that a run of some success could occur under these conditions. Spawning success in tributary waters would probably be reduced, however, and young-of-the-year shad, alewife, and herring would have difficulties during the summer months. The net result would likely be substantial reductions in populations of anadromous fish for that year. In the case of the 1964-1966 drought, three years of poor production might occur.

It is, however, unlikely that such an event would destroy an established fishery. Recovery would require several full breeding cycles, but the historical presence of these anadromous species in the Merrimack indicates that such natural fluctuations can be sustained by established populations. Additionally, restocking following such a rare event could reduce recovery time substantially.

Diversion Effects

As would be expected, low flow years present far more restrictions on withdrawals than an average year. In particular, no diversions at all would be possible during March and from June to November for the hypothetical day year (or for observed conditions during 1965). Limited diversions could occur in January, May, and December. The maximum diversion rate of 2,000 cfs would be possible during February and April for the hypothetical dry year, and only during April for 1965 flows.

Thus, while some diversions would be possible, even during conditions as severe as the 1964-1966 drought, these would be restricted to the winter and early spring months.

High Flow Conditions

Extreme high flow years present essentially no restrictions to diversion up to the maximum limit. The 10-year high average flows (See Table 3.1) are all much greater than 2,000 cfs above required flows, except during August and September, when the 10-year high average is 5,000 cfs, allowing a diversion of 1,500 cfs.

6.4 Potential Diversion Volumes

The results of the preceeding two sections allow the computation of total annual volumes which could be removed from the Merrimack without endangering the river's aquatic resources. Assuming that the maximum allowable rates are drawn continuously during each month, the total annual volume which might be withdrawn during an average year is about 3.8 x 10 cubic feet, or 0.86 million acre-feet. Ten-year low-flow conditions would reduce this to 0.45 million acre-feet. Ten-year high-flow conditions would allow nearly continuous withdrawal at 2,000 cfs and would increase the potential yeild to just over 1.2 million acre-feet.

6.5 Effects at the Withdrawal Site

The physical forces that can be expected to be operating in the vicinity of the withdrawal plant will adversely effect all major classes of vertebrates. Amphibians, reptiles, and aquatic birds and mammals that might be swimming near the intake could be pulled into the opening with the diverted flow. The young of these groups of animals would be particularly vulnerable to this type of occurrence. Fish, including year-round residents and especially migrating species proposed for restoration, would be more affected by this impact than any other class of aquatic vertebrates.

Of the anadromous species to be restored, the shad alone is capable of spawning in the fresh water reaches of the river; in the lower reach striped bass and sturgeon may, in the future, find suitable conditions for spawning if current pollution abatement schedules are followed. The anadromous fish restoration study conducted by the Massachusetts Division of Fisheries and Game (Oatis) notes that the Massachusetts section of river having the highest diversity of fish species is that which extends from the New Hampshire stateline to the dam at Lowell. From Lowell to Lawrence the river habitat for sports fisheries deteriorates. Silting is cited as a significant factor contributing to the decline in diversity of fish species. Below Lawrence, conditions in the river deteriorate further because of heavy pollution loads emanating from Lawrence, Haverhill and Amesbury; here fish productivity and diversity are the lowest of the three zones. The results of this study indicate that the stretch of river that would be most suitable for shad spawning in Massachusetts is the section between the Pawtucket Dam and the New Hampshire line. (Reach 1)

Since shad produce semi-bouyant eggs that are carried along the bottom of a river with subsurface flow, the eggs are dispersed as soon as they are deposited. The fry hatch after from 1 to 4 days and remain in the vicinity where they were hatched until fall migration. (See Appendix D) The adults immediately migrate downstream to the ocean. If the Tyngsborough location for the diversion facility were chosen, mortality of shad eggs would likely occur due to spawning in the vicinity of the intake. Mortality to eggs and fry would also result from eggs deposited further upstream being carried down and hatching near the intake. This would be much less likely to occur at Lowell because of the lower suitability of spawning conditions for shad spawning in this section. Additional mortality to shad eggs, and perhaps to juveniles, might be expected in low dissolved oxygen zones behind the dams. This too, indicates a selection of an intake in the vicinity of the dam, since shad habitat is marginal already at these locations. Mortality of shad eggs would be lower with reduced pumping velocities and with the intake opening located as near the surface as possible rather than near the bottom, where most of the eggs would be found. Mortality to benthic macroinvertebrates from being dislodged and carried into the plant would also be lower with the opening near the surface rather than near the bottom.

Adult upriver-migrating salmon, shad, alewives, and blueback herring would not be affected by water being pumped into the intake since they exhibit positive rheotaxis and would naturally tend to move away from the intake. However, the young fish moving downriver exhibit negative rheotaxis, and would be drawn to velocities in the vicinity of the intake that would be higher during the pumping phase than in the main body of the river. (McCann) The steeper the velocity gradient between the natural range of discharge rates occurring in the river during the downstream migration period and the velocity at the intake, the greater the tendency for young fish to be attracted to the intake opening. Natural summer velocities in the Merrimack are about one foot per second. Mortality of young fish during downriver migration could be reduced by providing intake velocities less than natural velocities. A peak velocity at the inlet mouth of 0.5 feet per second during low flow periods should allow fish to pass. Screens, facilities to guide the fish away from the intake, and other protective devices should also be used to reduce mortality of young fish. In summary, the effects of diversion on organisms occurring in the vicinity of the diversion facility can be lowered if the following points are considered:

The further downriver the facility is located, away from productive shad spawning habitat in Reach 1 and in New Hampshire, the lower the impact.

The Lowell location is more favorable than the one at Tyngsborough due to the lesser amounts of shad spawning habitat.

If the Lowell location is selected, the intake should be as far upstream of the dam as possible to avoid interference with fish congregated above the dam.

The intake opening should be located near the surface for reduced mortality of shad eggs and benthic macroinvertebrates.

Velocities at which water enters the plant should approximate natural discharge rates in the river during spring, summer, and early fall months that young fish are moving down. This will also reduce mortality to eggs during the period shad are spawning.

Water must not be less than 3 feet deep over suitable shad spawning habitat.

Screens and facilities to guide the fish past the intake should be installed; this will also reduce mortality to surface swimming herpetofauna, birds, and mammals.

7.0 CONCLUSIONS

The foregoing discussion of the influences of various withdrawal rates on the Merrimack River has demonstrated that substantial diversions are possible without compromising proposed anadromous fish restoration programs. This may be accomplished by a diversion policy which does not allow river flow to fall below the required flows derived in Section 6.1 and by an inlet structure design which is sensitive to the requirements of anadromous fish and other river life forms.

As indicated in Section 6.4, adherence to this policy will allow diversion of approximately 0.9 million acre-feet of water from the Merrimack during an average year.

In order to insure that adverse effects do not accrue to the proposed anadromous fishery (which will have a value of between $1,500,000 and $3,000,000 per year) the following suggestions are offered.

1) The following required flows should be maintained at all times:

January	2,000 cfs
February	2,000 cfs
March	6,000 cfs
April	6,000 cfs
May	4,000 cfs
June	4,000 cfs
July	3,500 cfs
August	3,500 cfs
September	3,500 cfs
October	3,500 cfs
November	3,500 cfs
December	2,000 cfs

When river flow is above these levels, diversion should not reduce flow to less than the required flow. When natural flow is at or below these levels, no diversion should occur.

2) "Peak chopping" (large removals during short-duration high flows) should not be allowed. This is especially true during March, April, May, and June, when such flows trigger migrating anadromous fish to begin moving upstream.

3) Any diversion plant should include continuous sensing of river flow to insure that control flows are not violated.

4) Any inlet structure should be designed such that the inlet velocity does not exceed 0.5 feet per second during low flow periods. A design based on 1.0 foot per second at 2,000 cfs should insure this.

5) In selecting a location for the diversion works, Lowell should take precedence over Tyngsboro. In general, locations further downstream are favored over upstream locations.

If carried out in conformity with the policy and engineering constraints discussed above, water diversions from the Merrimack River can be used to augment regional water supplies without compromising other existing or proposed uses of the Merrimack.

APPENDIX A

PHYSICAL CHARACTERISTICS, MERRIMACK RIVER

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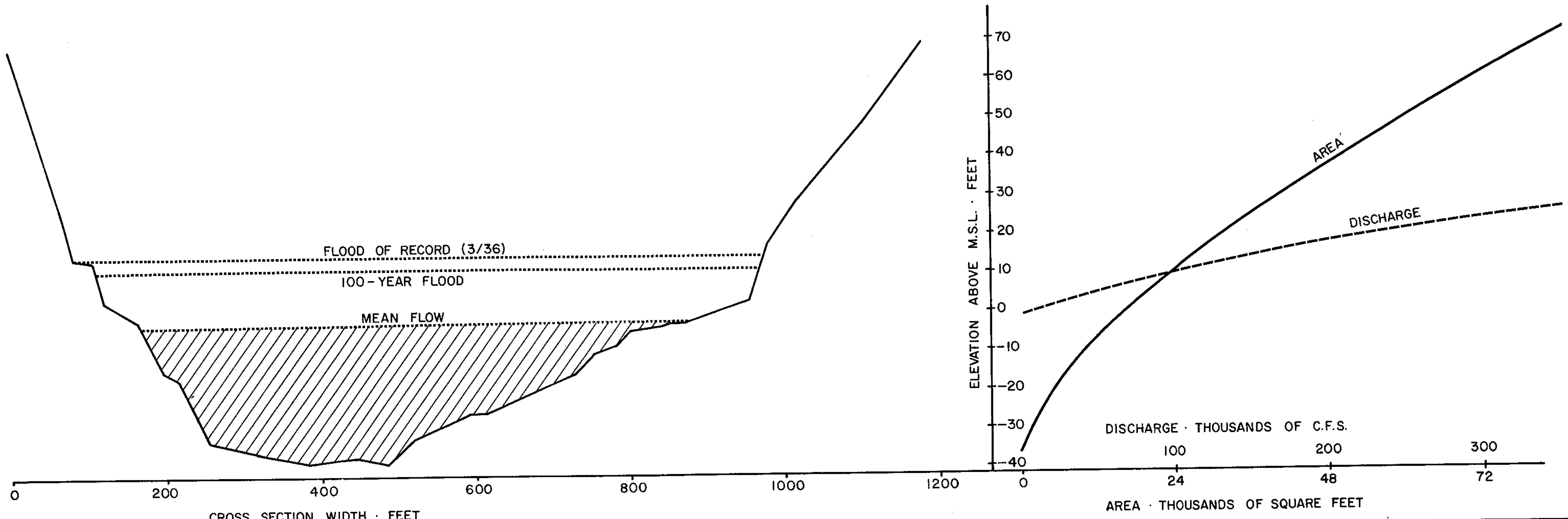

Figure A-1

Cross Section and Stage Discharge Relationship at Location A (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

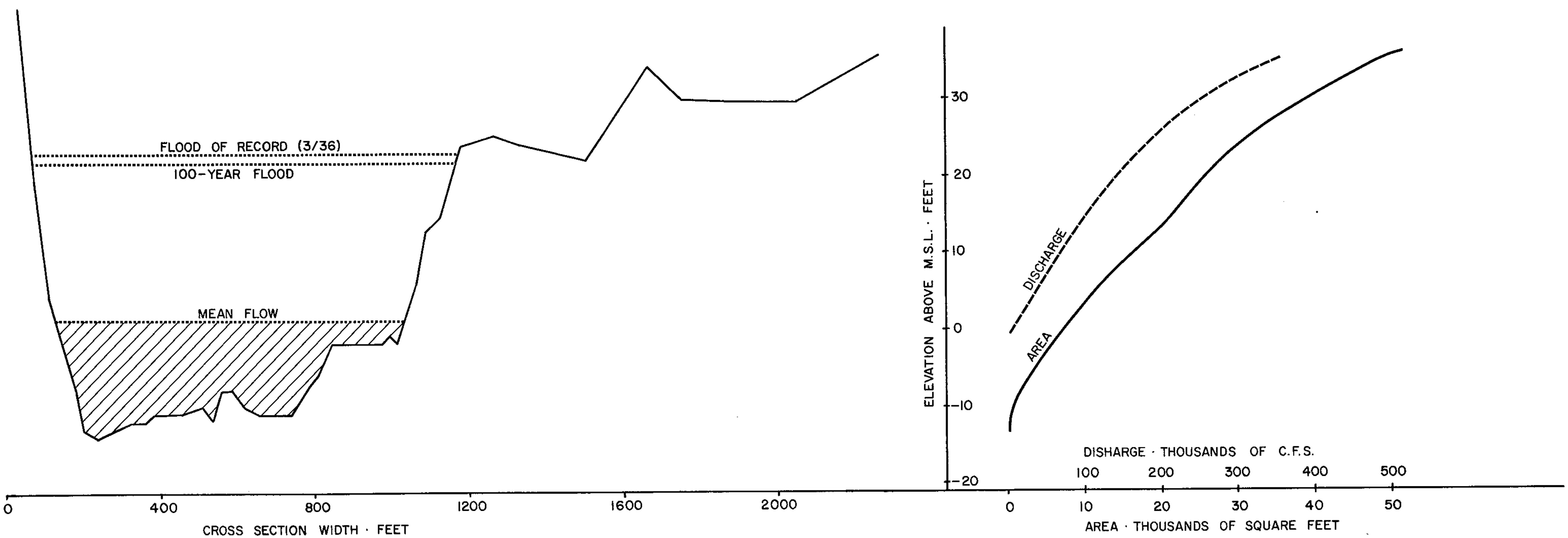

Figure A-2

Cross Section and Stage Discharge Relationship at Location B (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

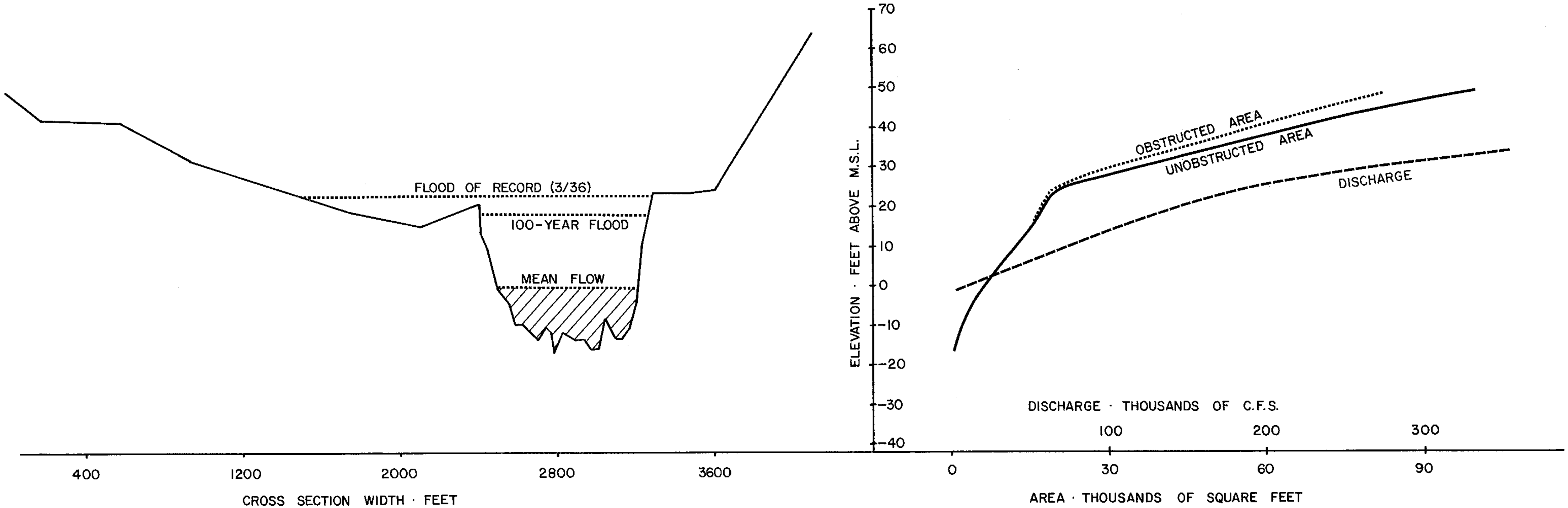

Figure A-3

Cross Section and Stage Discharge Relationship at Location C (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

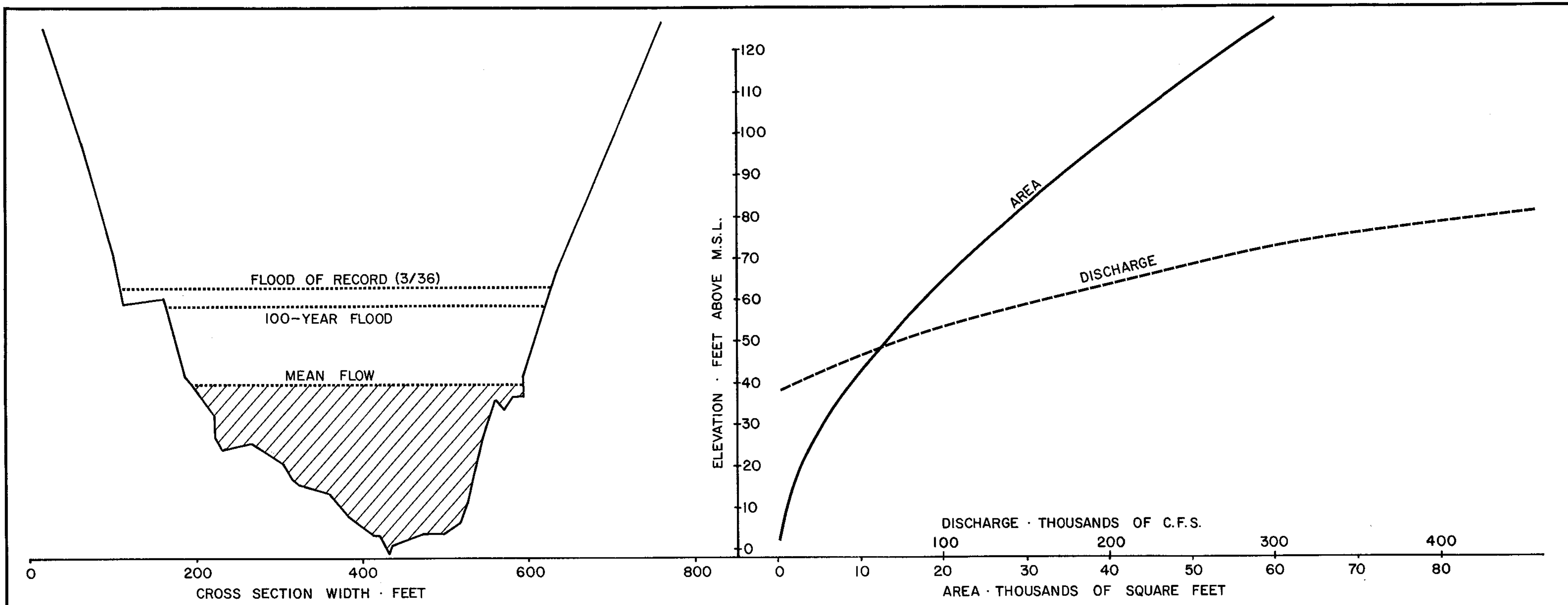

Figure A-4

Cross Section and Stage Discharge Relationship at Location E (see Figure 3)

Merrimack River Diversion Study

NOTE: DATA FROM U.S. ARMY CORPS OF ENGINEERS

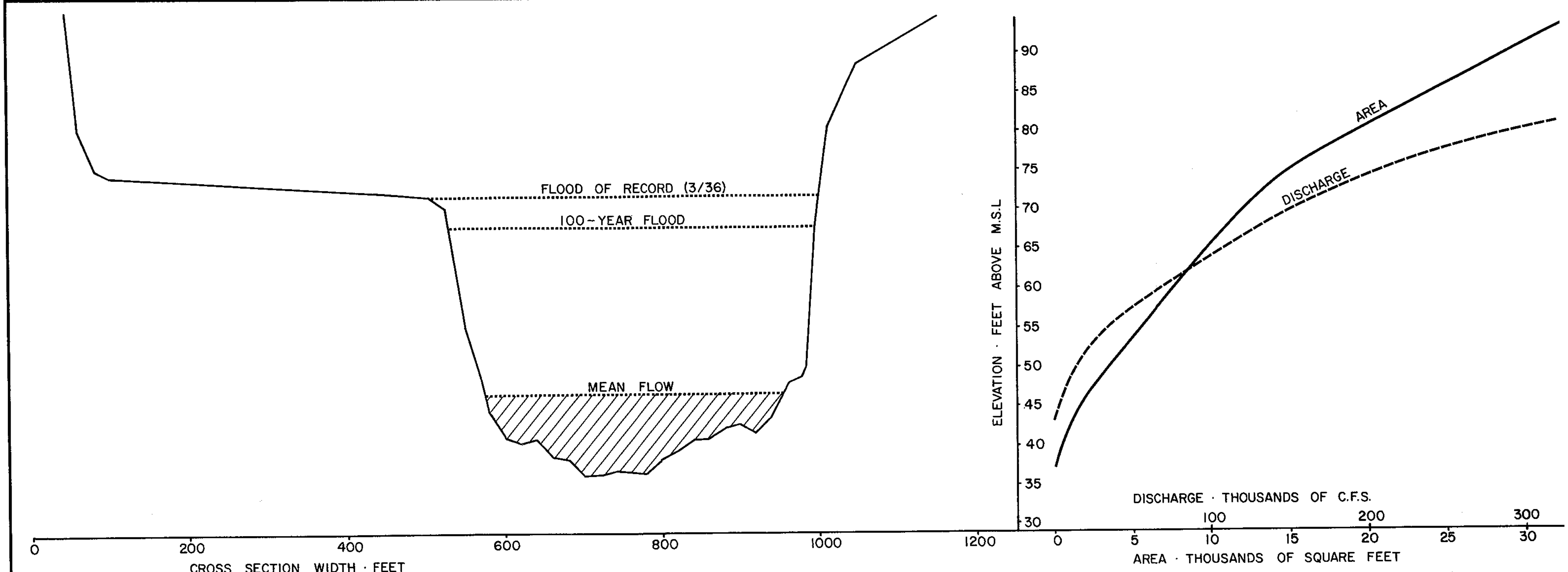

Figure A-5

Cross Section and Stage Discharge Relationship at Location F (see Figure 3)

Merrimack River Diversion Study

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DISCHARGE, MERRIMACK RIVER

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TABLE B.1

Mean Weekly Discharges (cfs) at Reaches 1, 2, and 3 from 1968-1973. Data Based on U.S.G.S. Gaging Station Data on Merrimack, Concord, and Shawsheen Rivers. See Fig. 2 for Gaging Locations.

		1968			1969			1970		
	Wk.	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3
Oct.	1	2782	3050	3086	1636	1690	1696	1797	2010	2029
	2	2525	2700	2714	1923	1990	1999	1792	1990	2007
	3	2406	2560	2573	1909	1990	1995	1694	1870	1886
	4	3250	3440	3455	2004	2090	2094	2234	2390	2406
Nov.	1	3243	3430	3442	1904	2010	2018	6171	6540	6613
	2	2911	3090	3104	3918	4370	4460	17039	18100	18316
	3	2988	3300	3336	5488	6060	6136	10890	11840	11936
	4	5312	5830	5895	5764	6170	6211	7672	8350	8415
Dec.	1	4721	5240	5303	13323	13860	13946	4867	5730	5777
	2	8299	8960	9031	8631	9250	9301	13687	14740	14899
	3	6844	7500	7550	8672	9500	9578	7869	8980	9062
	4	4920	5410	5450	5603	6290	6339	17214	18800	19146
Jan.	1	4408	4860	4897	4827	5370	5410	12847	14500	14620
	2	3924	4330	4368	4227	4650	4687	7892	9000	9068
	3	4040	4580	4643	4085	4470	4517	6418	7220	7271
	4	3717	4280	4343	6045	6750	6829	5986	6570	6619
Feb.	1	5922	6750	6889	5726	6320	6382	15958	17410	17668
	2	4428	5190	5250	4827	5250	5281	24967	27400	27598
	3	3508	3950	3985	4778	5230	5266	16364	18300	18387
	4	3066	3390	3421	5251	5670	5706	6357	7710	7775
Mar.	1	3084	3480	3517	5487	6040	6083	7204	8230	8292
	2	3495	4170	4268	5488	6110	6161	6308	7160	7229
	3	28909	32290	32726	7019	7940	8096	7370	8270	8378
	4	27827	31290	31420	22194	24790	25191	16154	17540	17670
Apr.	1	19489	21300	21376	20940	23390	23569	22819	25010	25244
	2	8786	9830	9887	33202	35060	35160	22300	24200	24296
	3	8648	9390	9459	36556	38010	38155	20746	22000	22070
	4	16544	17290	17364	35050	36680	36796	22050	23200	23288
May	1	8024	8600	8647	20783	21940	22004	14235	15000	15052
	2	6095	6570	6620	13900	14740	14798	7858	8380	8430
	3	13829	14440	14510	10724	11270	11215	14216	15100	15234
	4	11167	11770	11827	6489	6880	6909	7620	8310	8356
June	1	11309	11860	11915	4360	4610	4631	4978	5560	5624
	2	10202	10810	10897	3319	3470	3486	3723	4310	4354
	3	10373	11240	11325	5938	6050	6065	2460	2740	2760
	4	12536	13480	13600	5398	5510	5526	2196	2490	2523

TABLE B. 1 (continued)

	1968			1969			1970		
	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3
July 1	11575	12650	12729	2291	2360	2367	2714	3030	3062
2	4203	4850	4887	1872	1960	1975	2116	2300	2317
3	3367	3780	3810	1861	1960	1970	1831	1960	1972
4	2059	2250	2267	3812	3910	3923	1395	1520	1528
Aug. 1	2077	2210	2228	10506	10790	10826	1729	1810	1816
2	1961	2110	2135	5731	5920	5936	1315	1380	1386
3	1465	1540	1548	3397	3480	3486	1186	1300	1320
4	1440	1500	1504	2500	2550	2554	1589	1790	1813
Sept. 1	1246	1300	1304	2170	2220	2223	1299	1410	1421
2	2077	2160	2176	4004	4270	4309	1442	1540	1549
3	1607	1670	1677	2081	2260	2282	1791	1980	1999
4	1413	1460	1465	1666	1830	1845	1772	1890	1901

TABLE B.1 (continued)

Mean Weekly Discharges (cfs) at Reaches 1, 2, and 3 from 1968-1973. Data Based on U.S.G.S. Gaging Station Data on Merrimack, Concord, and Shawsheen Rivers. See Fig. 2 for Gaging Locations.

		1971			1972			1973		
	Wk.	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3
Oct.	1	2391	2503	2515	1328	1400	1406	1856	2035	NOT AVAILABLE FROM U.S.G.S.
	2	1931	2017	2027	2477	2670	2690	4098	4586	
	3	2701	2819	2838	2026	2140	2149	2726	3008	
	4	4569	4873	4910	2278	2400	2418	2283	2503(7)	
Nov.	1	3002	3268	3304	2243	2400	2420	4527	4875	
	2	3008	3311	3347	2160	2330	2347	7757	8691	
	3	4930	5351	5398	1916	2100	2119	8624	9885	
	4	5029	5378	5410	2009	2340	2403	15550	16937(6)	
Dec.	1	5489	5883	5926	3231	3750	3803	12100	13550	
	2	4438	4810	4838	4299	4960	4999	13817	15600	
	3	4213	4654	4697	4706	5220	5253	9278	10683	
	4	4020	4469	4505	4904	5390	5428	8373	9729(7)	
Jan.	1	3952	4409	4442	4313	4810	4856	10805	12228	
	2	3827	4214	4246	4741	5360	5424	7337	8265	
	3	3362	3679	3699	4805	5350	5387	11979	13040	
	4	4086	4404	4431	4681	5160	5198	18493	19729(7)	
Feb.	1	3420	3705	3728	4567	5110	5172	27269	28975	
	2	4376	4795	4852	5131	5780	5850	12237	13550	
	3	5962	6750	6850	6715	7430	7474	8702	9650	
	4	5233	6148	6249	4962	5600	5634	7590	8420(4)	
Mar.	1	7275	8638	8784	7937	9360	9630	8523	9378	
	2	6254	7629	7752	6819	8710	8869	20727	21838	
	3	10972	12825	13020	18647	21410	21737	28874	30013	
	4	8729	10343	10447	19814	22770	22921	17412	18371(7)	
Apr.	1	17615	19013	19089	16299	18200	18298	30486	32063	
	2	23671	25000	25096	15135	16440	16526	21058	22888	
	3	22315	23300	23364	29400	30700	30821	15152	16250	
	4	18142	18917	18972	24718	26100	26197	15705	16717(6)	
May	1	22212	23000	23079	24492	25810	25920	13452	14425	
	2	18221	19175	19281	18744	20330	20450	13742	14625	
	3	12926	14063	14156	18279	19780	19896	18481	19438	
	4	8044	8850	8899	8510	9600	9660	16958	17871(7)	
June	1	5035	5589	5637	12850	14100	14288	11257	11945	
	2	3224	3584	3624	8562	10100	10285	6485	7021	
	3	1939	2148	2169	5360	6540	6627	6529	7033	
	4	2295	2462	2486	8863	10020	10103	6825	7368(6)	

TABEL B. 1 (continued)

	1971			1972			1973		
	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3
July 1	1879	1989	2001	6729	7660	7717	28125	29238	
2	1274	1344	1352	5439	6100	6132	17052	17715	
3	1156	1255	1273	5830	5930	5974	5829	6249	
4	1605	1697	1707	7390	7910	7979	3082	3483(7)	
Aug. 1	2912	3080	3107	3743	4050	4075	6713	7241	Not Available
2	1936	2030	2038	2593	2830	2849	4093	4454	
3	1525	1624	1631	2051	2230	2242	2213	2534	
4	1551	1643	1651	2514	2630	2639	1691	1870(7)	
Sept. 1	1718	1792	1797	2623	2840	2883	1766	1935	
2	1807	1936	1947	1655	1860	1877	1790	1952	
3	2412	2575	2584	1508	1720	1374	1890	2146	
4	1869	1963	1969	2065	2240	2249	2384	2622(6)	

TABLE B.2

Mean Weekly Flow Rates (cfs) of Merrimack River from 1927-1967. Data from U.S.G.S. Gage on Merrimack River at Lowell, Massachusetts. Data based upon calendar years.

TABLE B.2

AVERAGE WEEKLY FLOW RATES CFS 1927

		1	2	3	4	5
1	4114	23714	7857	3375	4305	13542
2	3507	25057	6705	2961	8035	8428
3	3958	12142	5021	2525	7984	
4	6111	9957	3810	2600	8202	
5	6187	8020	2462	6655	32767	
6	4890	8611	2443	8000	11357	
7	4227	10201	2215	4180	15485	
8	4430	5985	2840	3740	13314	
9	5491	6145	4128	2925	13871	
10	7035	8057	3001	3065	18414	

AVERAGE WEEKLY FLOW RATES CFS 1928

		1	2	3	4	5
1	9628	7612	14900	7167	2987	4610
2	8385	8270	15142	7325	3130	4131
3	6972	14428	12157	5104	4120	
4	9345	12542	12171	3781	3588	
5	7284	21128	7934	9065	3597	
6	6838	12200	7565	7215	3310	
7	10454	15814	9802	5244	4231	
8	9782	22657	4935	5874	3194	
9	8294	14557	5308	4824	4087	
10	5394	8690	5870	3697	3577	

AVERAGE WEEKLY FLOW RATES CFS 1929

		1	2	3	4	5
1	4920	19028	13528	1700	1531	2781
2	6310	25242	7860	1583	1384	2477
3	6790	19842	4695	2064	2300	
4	7034	16757	3857	1698	1822	
5	4457	17928	3855	1402	1678	
6	8415	20857	4884	1535	2294	
7	6021	23742	3301	2018	3380	
8	4515	26142	2604	1787	2000	
9	5055	18814	2175	1248	1672	
10	11777	15657	1939	1647	1538	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1930

		1	2	3	4	5
1	2715	11845	5375	2005	1101	1789
2	6611	8527	5954	1748	1164	1955
3	5058	16914	3652	3072	1625	
4	3465	11497	7117	2697	1944	
5	2684	14842	6224	1891	1935	
6	2697	9630	3607	1832	2407	
7	3115	6954	2652	1685	4981	
8	6890	6794	2313	1440	3268	
9	9650	6508	2197	1220	3307	
10	11337	4945	1938	1079	2395	

AVERAGE WEEKLY FLOW RATES CFS 1931

		1	2	3	4	5
1	1890	5684	10752	2318	1520	4404
2	1991	7760	7812	1889	2177	9370
3	1807	18171	8868	3252	2077	
4	1666	22185	19128	2087	3641	
5	1661	24457	10410	2174	2412	
6	1570	13200	4962	2066	2678	
7	2134	11287	2891	1891	3435	
8	2540	8670	3617	1584	2462	
9	2994	8804	2750	2708	2318	
10	4330	10322	4668	2115	2992	

AVERAGE WEEKLY FLOW RATES CFS 1932

		1	2	3	4	5
1	4340	6184	4112	1642	6195	4261
2	9065	4954	4042	2612	4940	5904
3	13542	8710	3034	2297	10175	
4	8977	25742	2432	2072	7712	
5	8894	31642	1891	1556	8654	
6	6507	20228	1708	1426	14628	
7	7440	14514	2064	1421	16142	
8	5640	12300	3427	7481	8540	
9	5108	8147	2522	3117	6544	
10	8605	5812	1992	2831	5355	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1933

		1	2	3	4	5
1	5975	12185	7318	1715	5770	3532
2	5552	13385	6098	1666	4430	3455
3	6065	14742	4960	1727	5647	
4	8855	32767	3440	2592	5535	
5	6298	29957	3094	3288	3992	
6	5990	32767	2802	2207	3878	
7	5687	27657	1915	2494	3594	
8	7350	20185	1869	7514	4874	
9	7064	11985	1746	4355	5798	
10	11877	9260	1693	3734	3828	

AVERAGE WEEKLY FLOW RATES CFS 1934

		1	2	3	4	5
1	4251	9207	6435	2660	4415	4834
2	5901	10948	4274	1827	3718	4674
3	5168	15597	3964	1446	3825	
4	6070	32271	3707	1400	4192	
5	5950	32767	5554	1486	7445	
6	4105	31300	3407	1511	5372	
7	3608	20328	1909	2950	5361	
8	3265	15200	1797	7367	7068	
9	3720	14342	1431	3761	10620	
10	13771	9148	1783	4855	4188	

AVERAGE WEEKLY FLOW RATES CFS 1935

		1	2	3	4	5
1	3958	15328	5007	2637	1984	3728
2	21524	17328	5127	2481	1725	2520
3	10268	14942	6184	2320	1650	
4	8735	11644	11114	1855	1883	
5	7597	15537	14492	1681	2003	
6	6520	18542	9331	2862	3672	
7	6937	14814	4962	3601	3438	
8	7764	12482	7751	2890	6902	
9	8678	12337	4034	2207	4757	
10	10907	7745	3274	2465	4191	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1936

		1	2	3	4	5
1	4537	32767	5614	1795	2003	15488
2	5531	32767	3932	1634	4957	12950
3	9211	32767	3051	1691	4850	
4	6845	28000	2862	1560	4092	
5	5264	28171	3624	1664	5580	
6	4494	18242	2442	2224	3852	
7	4021	11725	1794	1744	2614	
8	4878	11722	2258	1753	2091	
9	4897	9150	2041	1591	3354	
10	5241	7807	1939	1862	12262	

AVERAGE WEEKLY FLOW RATES CFS 1937

		1	2	3	4	5
1	11325	7068	19400	2478	1601	9607
2	10558	12600	13385	2830	2545	7211
3	13318	8404	9681	2845	7434	
4	13357	10954	6638	2257	4860	
5	8342	16271	8685	2397	3101	
6	6454	20385	7618	2181	15075	
7	11545	20757	6090	2571	8634	
8	15447	21871	3632	2362	18178	
9	9638	17414	3285	2092	16681	
10	6100	25514	2478	2000	11085	

AVERAGE WEEKLY FLOW RATES CFS 1938

		1	2	3	4	5
1	5690	6955	8447	19928	6667	11135
2	7985	16190	5602	7832	5231	7892
3	5727	16128	4300	5724	9440	
4	15192	11387	6415	4874	7674	
5	14500	11591	4451	3915	5604	
6	14000	19314	5922	3425	5327	
7	10814	11002	5548	3775	8165	
8	8385	7782	3938	32767	7067	
9	6940	5342	6442	32767	19371	
10	7438	10041	14314	9932	25257	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1939

	1	2	3	4	5
1	7314	8840	8605	2325	1721	3205
2	11251	8737	7084	2121	1522	2822
3	7144	13528	4402	2043	1574	
4	5097	19671	3832	2480	5002	
5	4832	20371	3751	2234	4687	
6	4924	32400	3621	1732	3148	
7	5534	32767	3427	1971	2307	
8	7730	20685	2192	1816	1888	
9	10090	15771	1919	1434	4511	
10	11732	8260	1749	1876	2885	

AVERAGE WEEKLY FLOW RATES CFS 1940

	1	2	3	4	5
1	1892	3584	11014	3344	1993	5608
2	1763	5315	16185	2527	1763	5162
3	3454	5580	17324	1837	1543	
4	2325	21685	9144	1785	1954	
5	1842	32767	6404	1954	5298	
6	1921	31642	4655	3834	8795	
7	3008	27185	4505	2882	7041	
8	2571	31200	4402	2437	4071	
9	2511	26757	3454	2938	3544	
10	2947	12671	3620	2400	3888	

AVERAGE WEEKLY FLOW RATES CFS 1941

	1	2	3	4	5
1	10091	5197	2775	2308	1738	2300
2	5757	5264	2820	1389	1891	4455
3	4627	8707	2402	1236	1435	
4	4504	10858	1989	1386	2542	
5	4221	12771	3285	1212	3265	
6	9311	11757	1754	1408	2356	
7	10680	6187	1482	1356	1693	
8	6905	4651	3073	1200	1711	
9	5428	5471	3122	1030	1586	
10	5177	4354	2147	1110	1898	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1942

		1	2	3	4	5
1	4242	16557	6582	4254	2133	4337
2	2340	20114	4342	2570	1696	3610
3	3025	14000	3268	2852	2873	
4	4340	14914	10321	2204	4184	
5	2997	17271	10490	1732	4697	
6	2670	16457	4197	1566	4291	
7	2650	12471	4101	2231	5158	
8	3107	8590	3850	2013	9521	
9	3201	6670	2478	2278	12522	
10	12437	5617	2315	2365	6064	

AVERAGE WEEKLY FLOW RATES CFS 1943

		1	2	3	4	5
1	9015	12584	16757	3640	1634	3634
2	5000	14628	12088	5940	4832	3064
3	4360	18000	6947	6572	4264	
4	3894	11514	6241	4168	6242	
5	3651	10211	5732	2679	9477	
6	4324	13914	3784	2994	12540	
7	5034	18185	3195	3315	7547	
8	6788	20328	3032	2285	8151	
9	10345	18400	2219	1704	5592	
10	6557	20128	2697	2172	4808	

AVERAGE WEEKLY FLOW RATES CFS 1944

		1	2	3	4	5
1	2697	5011	5962	2906	3049	5545
2	2705	7510	4435	1983	2990	4392
3	2427	15191	2758	1759	4492	
4	2867	14371	3155	1630	2893	
5	3061	18971	5717	1671	2692	
6	2540	20200	29471	1748	4381	
7	2615	21685	7617	2389	3468	
8	3782	17528	4772	8914	4602	
9	3881	14442	3795	2978	7572	
10	3587	8530	2652	3202	8834	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1945

		1	2	3	4	5
1	10342	15414	19300	6292	4501	6581
2	6521	31471	11840	4074	3684	6950
3	5775	27314	8335	3041	3358	
4	5364	21828	7715	2511	3125	
5	4928	13661	16614	2585	3984	
6	5098	8242	13127	3086	3944	
7	5220	13258	6625	2277	10700	
8	6227	15614	4598	3210	7342	
9	10467	16514	7558	2805	13512	
10	14471	27828	5820	5755	14900	

AVERAGE WEEKLY FLOW RATES CFS 1946

		1	2	3	4	5
1	7760	27257	12200	4401	3865	3702
2	14085	19828	16528	4304	4184	4160
3	8105	16985	13514	4194	3777	
4	6380	13628	8634	3727	3520	
5	6305	9220	5007	3491	3894	
6	6311	6770	3150	3037	4842	
7	8234	9020	2908	3152	3794	
8	7695	8771	2478	2195	3990	
9	6535	9805	2141	3074	3500	
10	19615	13428	3252	10074	4584	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1947

		1	2	3	4	5
1	3981	15417	9665	3584	1242	3025
2	3652	13914	9671	2547	1103	2375
3	4268	14957	14228	2522	1134	
4	6550	16257	11071	2484	1102	
5	8804	23671	8394	2196	2089	
6	12355	17428	6124	2902	7515	
7	7528	13185	3248	2158	3330	
8	6457	17000	3098	2272	4321	
9	6684	18814	3365	1977	2672	
10	9098	10870	6715	1531	2411	

AVERAGE WEEKLY FLOW RATES CFS 1948

		1	2	3	4	5
1	2251	4342	20114	3185	1618	2805
2	2484	30057	16485	2307	1256	1992
3	2325	29514	11418	2652	1524	
4	2175	20285	13028	2105	1298	
5	2280	12157	9341	1748	2423	
6	2245	13957	6938	1502	4148	
7	2827	10451	5197	1529	6217	
8	5708	7904	6082	1390	5651	
9	4597	10577	3498	1079	3631	
10	3808	15214	3238	1137	3124	

AVERAGE WEEKLY FLOW RATES CFS 1949

		1	2	3	4	5
1	16142	7940	5295	1313	1761	3512
2	13648	7404	6748	1301	1674	4698
3	5828	16685	3707	1270	1574	
4	4910	10860	2432	1406	2526	
5	4681	11200	2059	2156	3095	
6	4557	12700	2205	1278	3055	
7	7348	11645	1431	1486	2601	
8	10538	9822	1816	1754	2962	
9	9681	8355	1726	2735	2738	
10	9138	4708	1590	1891	3231	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1950

		1	2	3	4	5
1	4600	6694	5472	1088	1994	6862
2	6494	7761	5375	1125	2808	4754
3	7461	19485	8831	1160	2016	
4	5341	22685	4112	1650	2035	
5	6920	14314	2921	1762	3730	
6	5364	16500	1966	2728	2231	
7	6312	20185	1417	1687	3338	
8	4992	12000	1920	1401	19458	
9	4317	8495	1395	1214	13401	
10	4881	6157	1331	1207	15654	

AVERAGE WEEKLY FLOW RATES CFS 1951

		1	2	3	4	5
1	6034	13187	6400	6264	7494	8875
2	6152	18142	11828	3892	4981	11308
3	6702	18628	6242	4347	5685	
4	9005	32767	5114	5557	11105	
5	7284	28814	5148	4400	27528	
6	14814	19171	4344	5780	14714	
7	12885	17542	3864	4232	10552	
8	18071	12742	4144	3974	9058	
9	11857	7758	5398	3515	11080	
10	10668	7314	4481	3247	10648	

AVERAGE WEEKLY FLOW RATES CFS 1952

		1	2	3	4	5
1	13042	14314	12771	1819	2571	8297
2	10577	12714	14500	2005	1848	5720
3	11942	16457	23471	3261	1854	
4	15857	28328	9412	2900	1482	
5	16971	32767	4630	1762	1476	
6	17342	29028	3665	2672	1451	
7	10765	20257	2644	1643	2562	
8	9645	18357	2675	1895	3740	
9	8318	9964	2464	1914	3292	
10	8464	17257	1943	2735	13841	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1953

		1	2	3	4	5
1	5002	28502	13800	1470	1325	8634
2	4498	24885	8075	2827	1461	6505
3	5768	32767	4610	2418	1863	
4	13472	32767	2922	1505	4124	
5	14128	23785	2312	1473	2307	
6	12145	27528	1927	1101	2340	
7	13090	19114	1555	1314	2750	
8	16000	22100	1572	1383	8335	
9	11747	18500	1815	1400	8738	
10	10527	18428	1770	1317	13557	

AVERAGE WEEKLY FLOW RATES CFS 1954

		1	2	3	4	5
1	4811	7801	24542	3448	5341	21257
2	4162	10285	15414	3161	8127	13257
3	3957	10517	14657	2700	5644	
4	5160	7840	9418	2158	8008	
5	5978	12414	6542	5261	13515	
6	5367	26428	5208	6621	7562	
7	4624	19928	5934	24555	15668	
8	11652	17342	3542	16842	14628	
9	15285	31828	2314	9998	10982	
10	14785	29528	2437	6447	11215	

AVERAGE WEEKLY FLOW RATES CFS 1955

		1	2	3	4	5
1	13314	14328	4255	1527	4000	4324
2	9638	10957	8051	1467	15012	2914
3	7092	10688	7400	5454	8420	
4	5808	16471	6818	9985	10525	
5	4735	17428	4771	6642	18757	
6	5765	19071	4534	4484	14871	
7	8877	16957	2712	3302	11375	
8	8107	15142	2512	2551	7641	
9	12457	9744	1936	2634	6508	
10	9495	6288	1835	2569	5422	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1956

		1	2	3	4	5
1	2264	8101	8517	2221	4080	7802
2	24004	7787	13288	1866	2844	7095
3	19328	7108	14857	1729	2788	
4	8221	11061	7611	1590	2598	
5	6620	22542	3740	1502	3028	
6	7204	32767	2870	2288	2529	
7	8208	26857	2150	2238	4250	
8	7005	32767	4104	2962	5572	
9	7432	19300	6275	4818	3448	
10	9015	12771	3058	2967	6537	

AVERAGE WEEKLY FLOW RATES CFS 1957

		1	2	3	4	5
1	5187	9822	6042	1407	1159	13385
2	5270	10392	4120	1249	1142	18900
3	4730	8575	3122	1258	1957	
4	11598	10842	2216	1062	2307	
5	8395	11571	1685	876	4785	
6	6591	8185	2218	789	4585	
7	5355	7752	2627	827	5780	
8	3984	5000	2415	988	3934	
9	9698	3484	1486	1077	4042	
10	7795	4895	1231	823	12114	

AVERAGE WEEKLY FLOW RATES CFS 1958

		1	2	3	4	5
1	9751	13357	9182	3340	2322	3565
2	6900	11785	6664	2176	1733	2684
3	6948	15400	6531	1936	3125	
4	15971	23628	4187	1772	4197	
5	19128	24257	2828	1777	3892	
6	11197	29557	2292	1533	4064	
7	8577	29114	1650	1448	3477	
8	7494	24800	2935	2158	5335	
9	9205	19928	2554	2774	6354	
10	10942	14171	2195	2698	4560	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1959

		1	2	3	4	5
1	2798	6817	4405	2662	4831	12657
2	2424	13127	3034	1887	2785	7915
3	2834	13442	3200	2158	14432	
4	8470	32767	2733	1371	13635	
5	4972	27428	5550	2444	9558	
6	5377	16471	4047	4297	9238	
7	4190	11240	2720	1998	8352	
8	4270	10211	2412	1965	22514	
9	3674	6828	3555	1680	13828	
10	9311	5757	4460	1887	18071	

AVERAGE WEEKLY FLOW RATES CFS 1960

		1	2	3	4	5
1	12080	6991	12347	3130	3151	5385
2	9800	7171	11821	2565	3015	4742
3	7500	7670	9757	2577	8378	
4	6692	32767	5621	2145	9494	
5	6478	32767	7102	1675	9160	
6	8090	29857	3991	1464	6361	
7	12771	20014	2957	9129	5084	
8	11171	15385	2370	7998	5557	
9	9098	11645	2795	5557	7387	
10	7888	17928	2290	4557	4488	

AVERAGE WEEKLY FLOW RATES CFS 1961

		1	2	3	4	5
1	4200	10154	7608	2661	2348	3258
2	3771	8377	9011	1774	2610	3041
3	3550	15737	5422	1551	2271	
4	3227	18642	6394	1471	1741	
5	3142	18071	4284	2428	3027	
6	3131	24785	3895	1828	3247	
7	3391	25214	2590	1742	3827	
8	5560	19000	2661	3057	5797	
9	13712	13757	3110	3848	4461	
10	13328	11424	2942	2764	3822	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1962

		1	2	3	4	5
1	3551	6561	8302	1789	21242	7588
2	5651	9188	6382	2284	7428	6372
3	5658	19785	5161	2474	5347	
4	5357	32767	3847	1962	8814	
5	4344	30400	2087	1705	9907	
6	3797	14742	2281	1634	13545	
7	2987	11132	1481	1486	9420	
8	3148	15142	1552	1814	8417	
9	3635	10482	1672	1897	15201	
10	3925	6970	2168	5831	13697	

AVERAGE WEEKLY FLOW RATES CFS 1963

		1	2	3	4	5
1	5718	7012	9292	1173	1213	5290
2	5701	9154	4832	1142	1056	4482
3	5485	25657	2831	1376	1153	
4	5944	30828	2411	1302	1556	
5	5141	17285	2451	1281	9458	
6	5241	14771	1643	1588	7677	
7	4681	12568	1315	1022	5038	
8	4685	11848	1527	1109	6872	
9	4361	9680	1377	1106	7120	
10	5510	8575	1304	1599	9261	

AVERAGE WEEKLY FLOW RATES CFS 1964

		1	2	3	4	5
1	4062	15971	5592	1145	860	1870
2	3880	11465	3038	953	800	3653
3	3884	12214	2091	993	1475	
4	16928	11071	1941	1144	1188	
5	12380	17685	1654	1726	1129	
6	9011	27957	1353	920	1180	
7	6784	16857	1492	1181	1316	
8	6072	10341	1528	1011	4420	
9	5572	7024	1500	1006	2385	
10	15092	6927	1427	930	1940	

TABLE B.2 (continued)

AVERAGE WEEKLY FLOW RATES CFS 1965

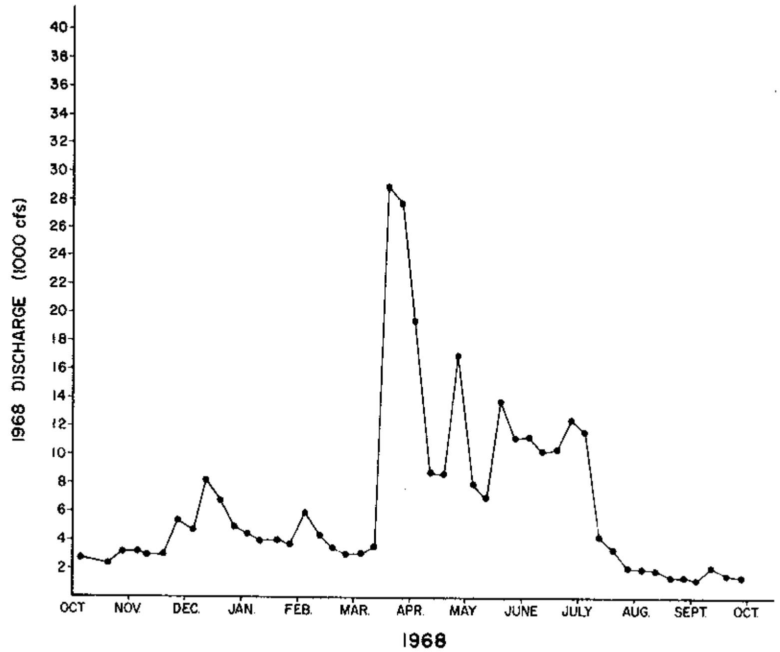
		1	2	3	4	5
1	3935	6440	3560	899	2435	2092
2	2942	4481	2300	723	2288	2495
3	1981	4181	2255	944	2191	
4	1761	3745	2707	995	1770	
5	1604	8204	2301	932	1471	
6	2829	14057	1564	1692	2414	
7	4090	9735	1092	1126	3720	
8	2860	8100	1421	1035	3682	
9	5482	5948	1168	1684	2897	
10	8378	4645	1022	2110	2150	

AVERAGE WEEKLY FLOW RATES CFS 1966

		1	2	3	4	5
1	3487	7890	9041	1083	1794	4441
2	2541	11017	5270	967	2705	3511
3	2285	16828	3405	1079	5677	
4	2350	9568	5335	1837	4322	
5	2224	8888	3552	1729	11298	
6	2218	9074	2103	2237	6921	
7	5997	9705	975	1566	4594	
8	5264	8338	1424	1418	4738	
9	5820	7697	1355	2524	4568	
10	10597	8962	1119	2101	5751	

AVERAGE WEEKLY FLOW RATES CFS 1967

		1	2	3	4	5
1	4194	6140	12971	3724	2424	7624
2	3738	5768	15057	3590	2504	5692
3	3314	8815	7334	2775	3165	
4	4058	28728	6177	2598	3181	
5	5112	22685	6917	2507	3678	
6	4070	24471	6952	1732	3010	
7	3555	20500	5898	1938	3874	
8	3525	15757	4241	1469	5132	
9	3171	17042	3802	1573	5651	
10	3198	16685	3621	3275	9494	



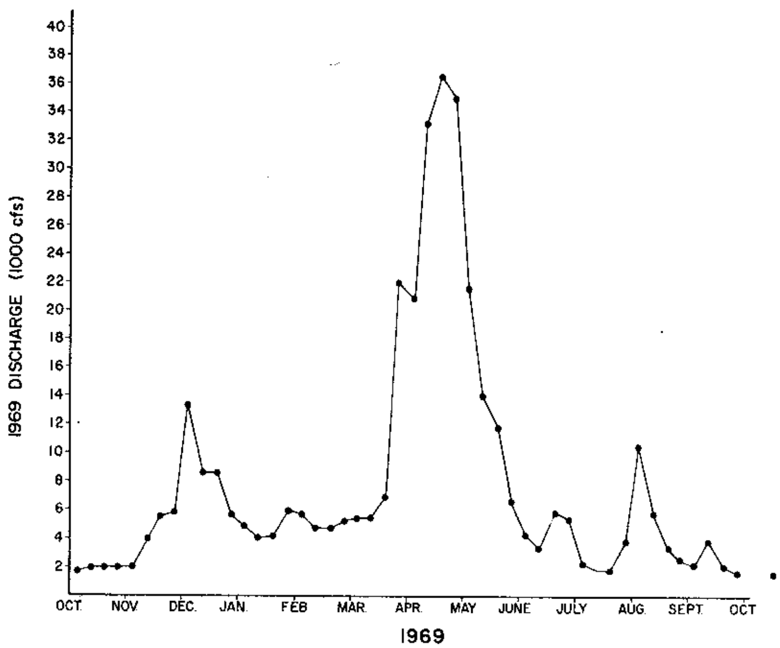
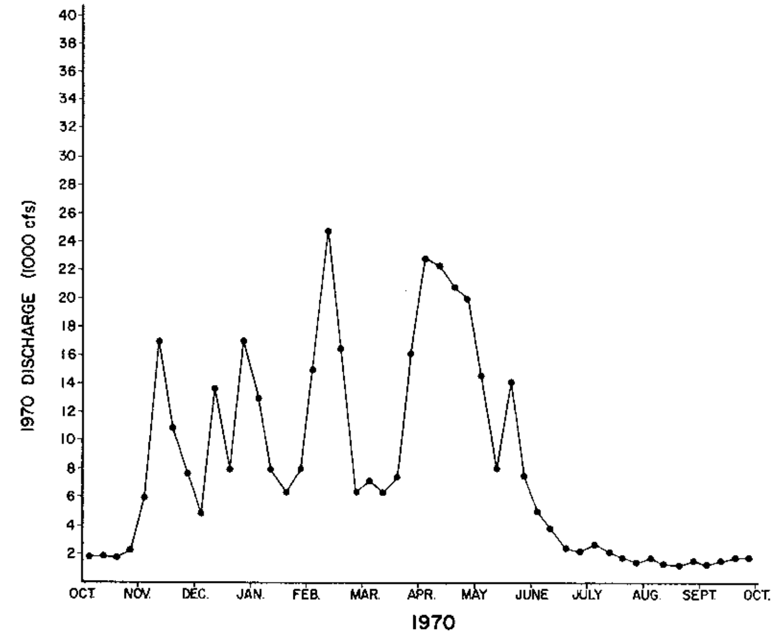


Figure B1-1
1968 and 1969 Mean Weekly Discharge
Reach 1 Merrimack River

Merrimack River Diversion Study



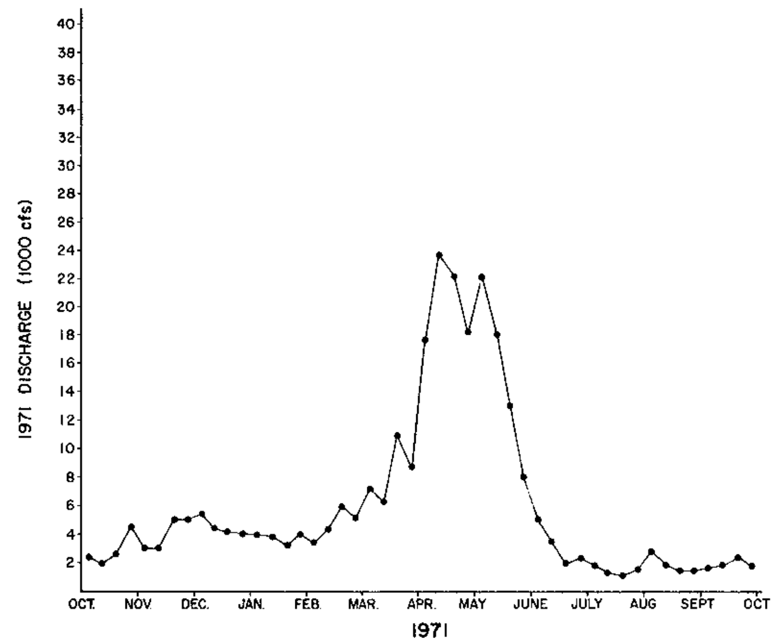


Figure B1-2
1970 and 1971 Mean Weekly Discharge
Reach 1 Merrimack River

Merrimack River Diversion Study

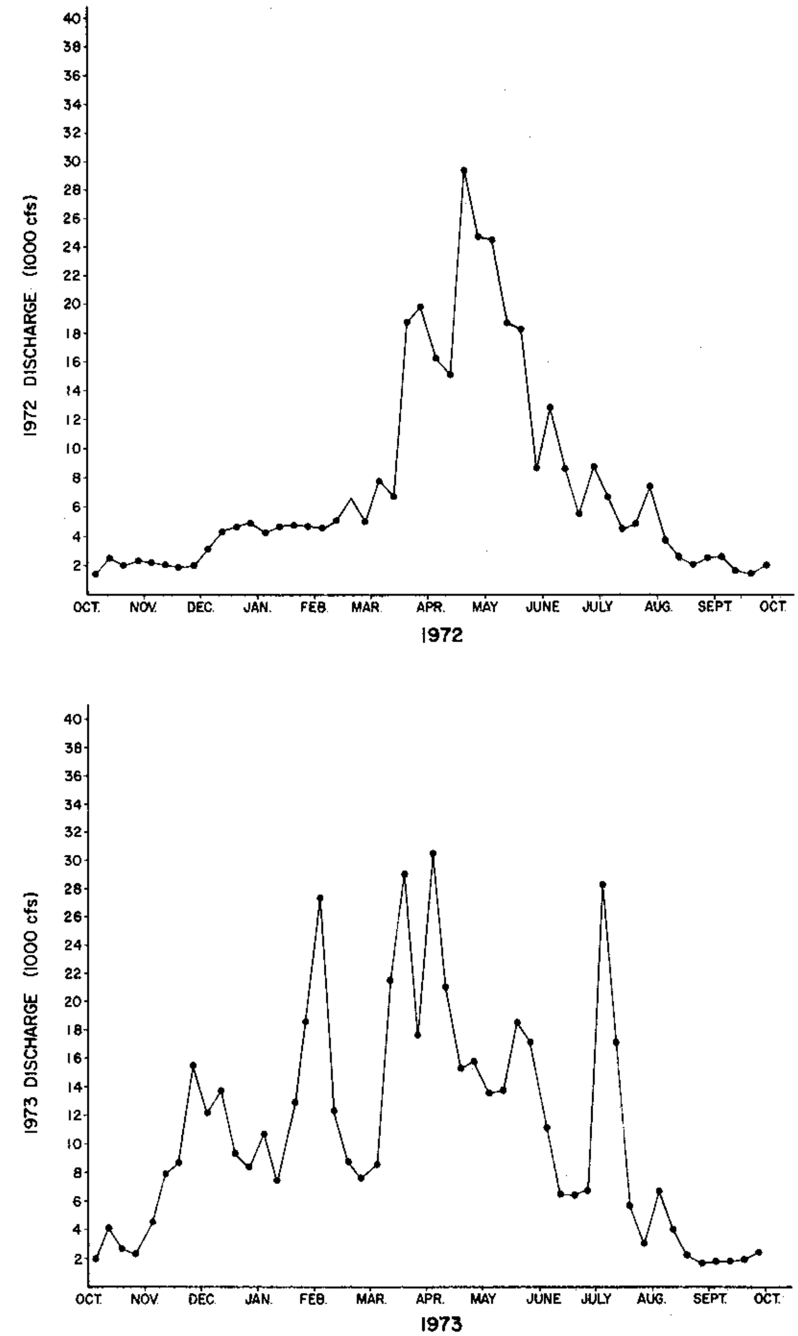


Figure B1-3
1972 and 1973 Mean Weekly Discharge Reach 1 Merrimack River

Merrimack River Diversion Study

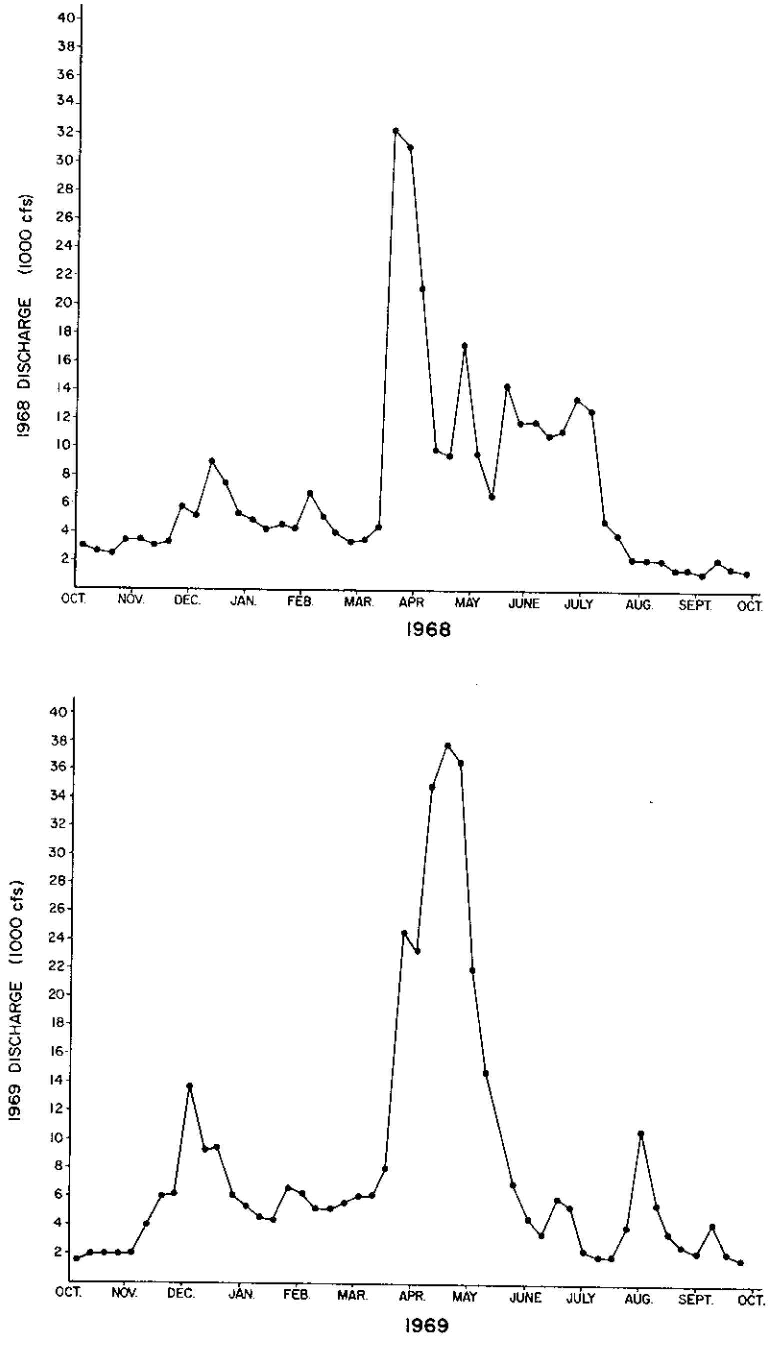
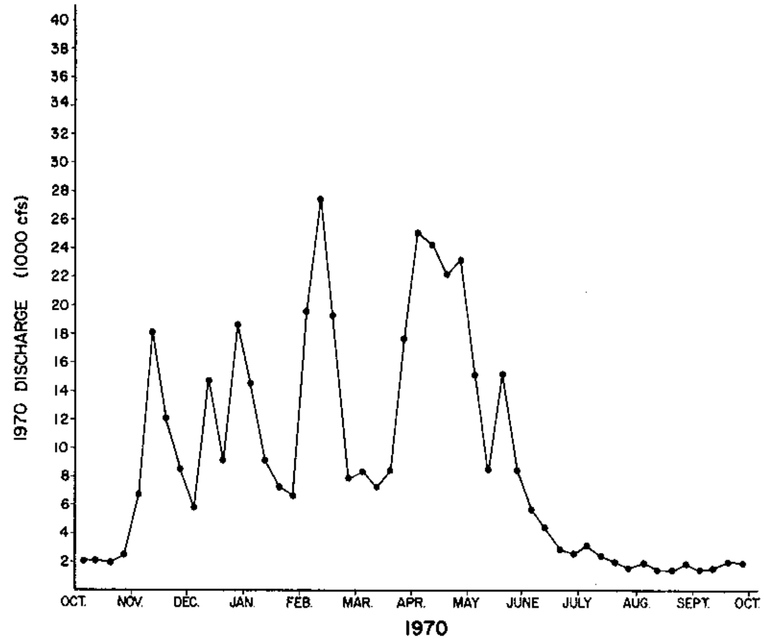


Figure B2-1
1968 and 1969 Mean Weekly Discharge Reach 2 Merrimack River

Merrimack River Diversion Study



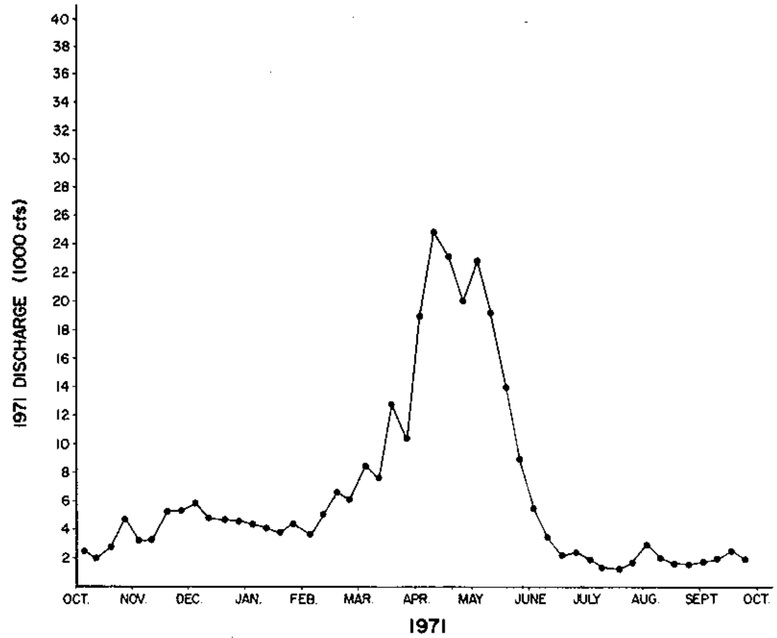
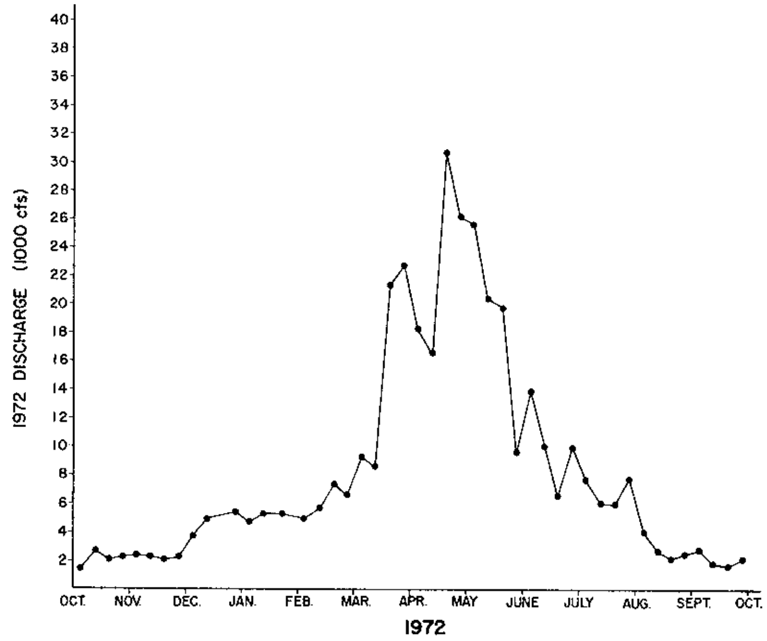


Figure B2-2
1970 and 1971 Mean Weekly Discharge Reach 2 Merrimack River

Merrimack River Diversion Study



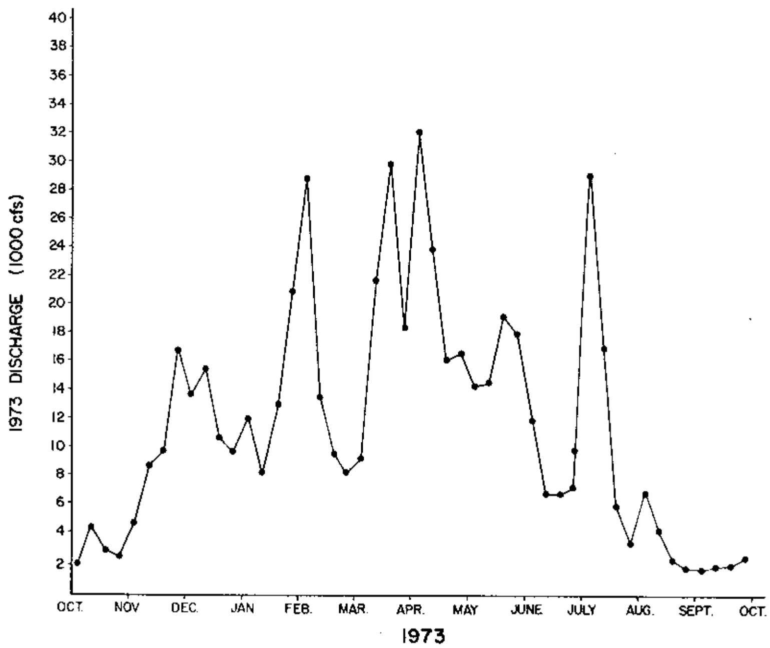


Figure B2-3
1972 and 1973 Mean Weekly Discharge Reach 2 Merrimack River

Merrimack River Diversion Study

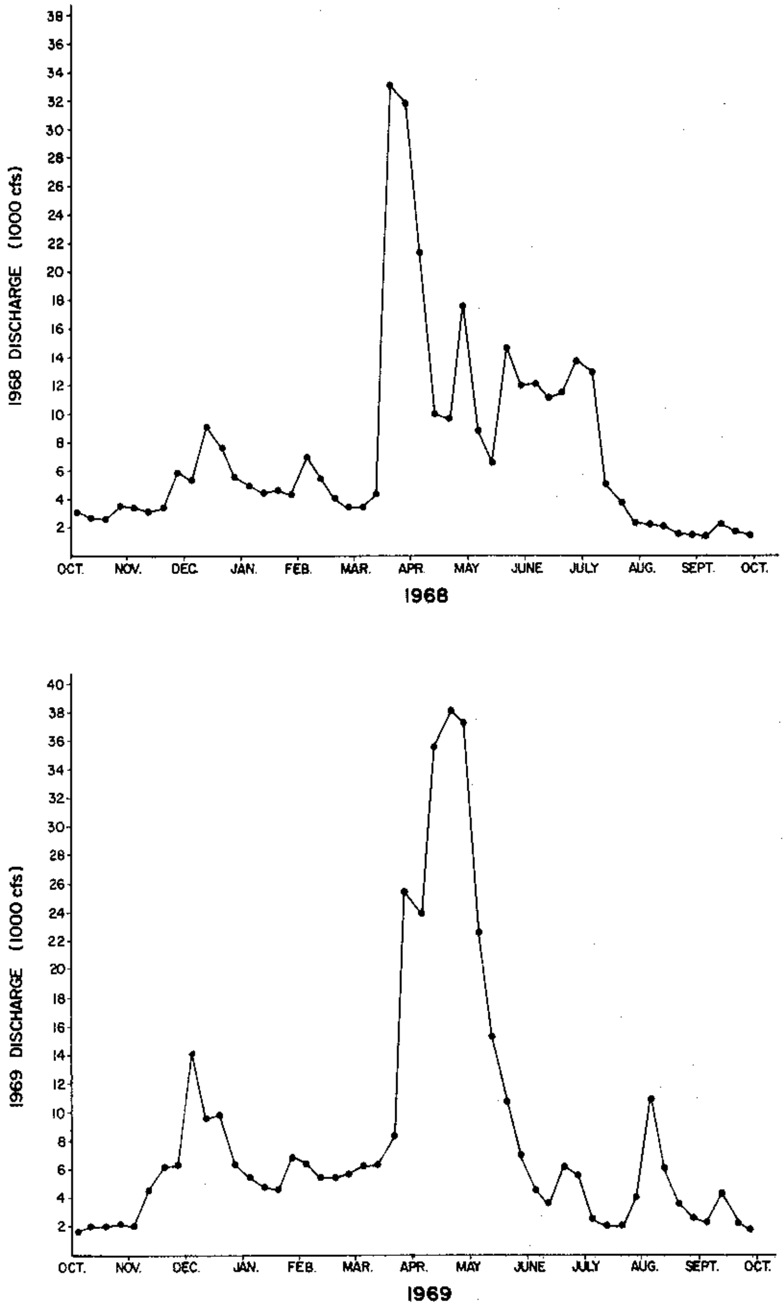


Figure B3-1
1968 and 1969 Mean Weekly Discharge Reach 3 Merrimack River

Merrimack River Diversion Study

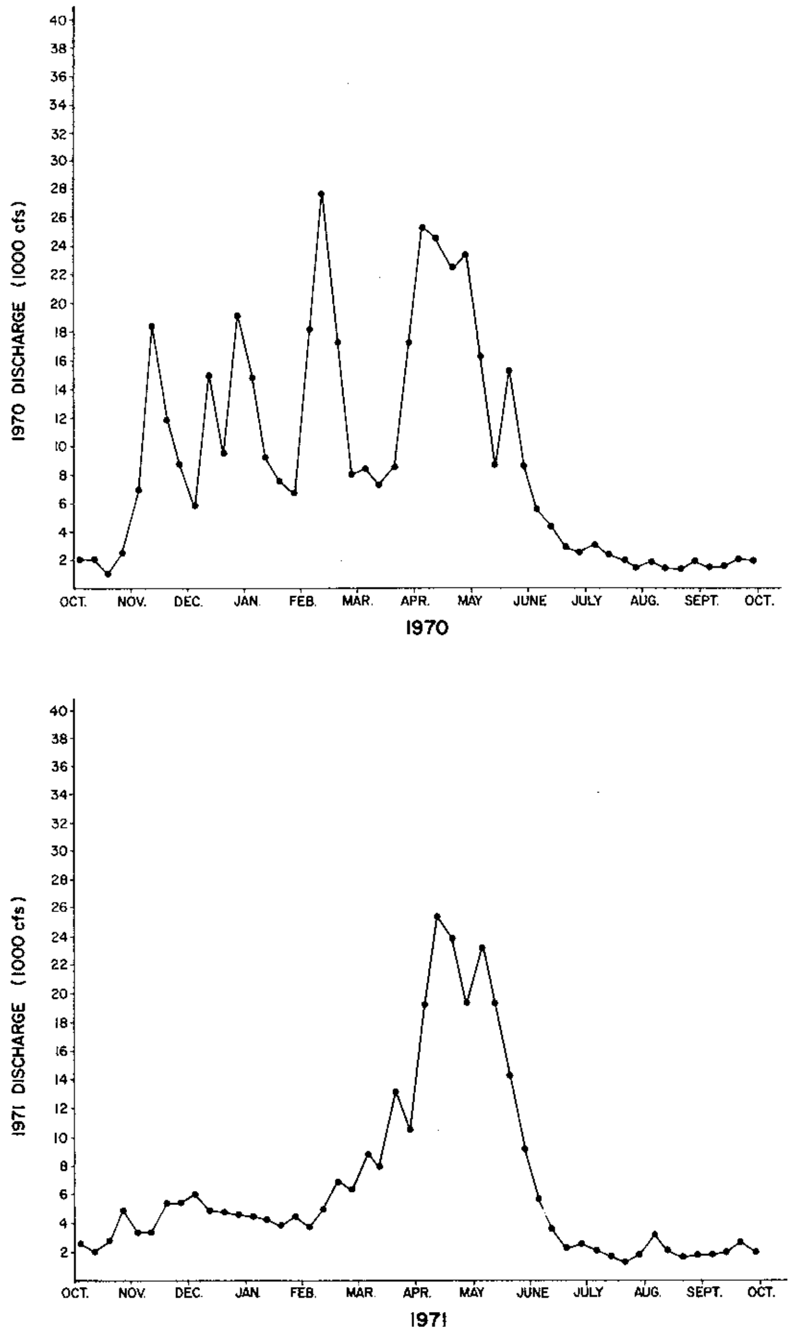


Figure B3-2
1970 and 1971 Mean Weekly Discharge Reach 3 Merrimack River

Merrimack River Diversion Study

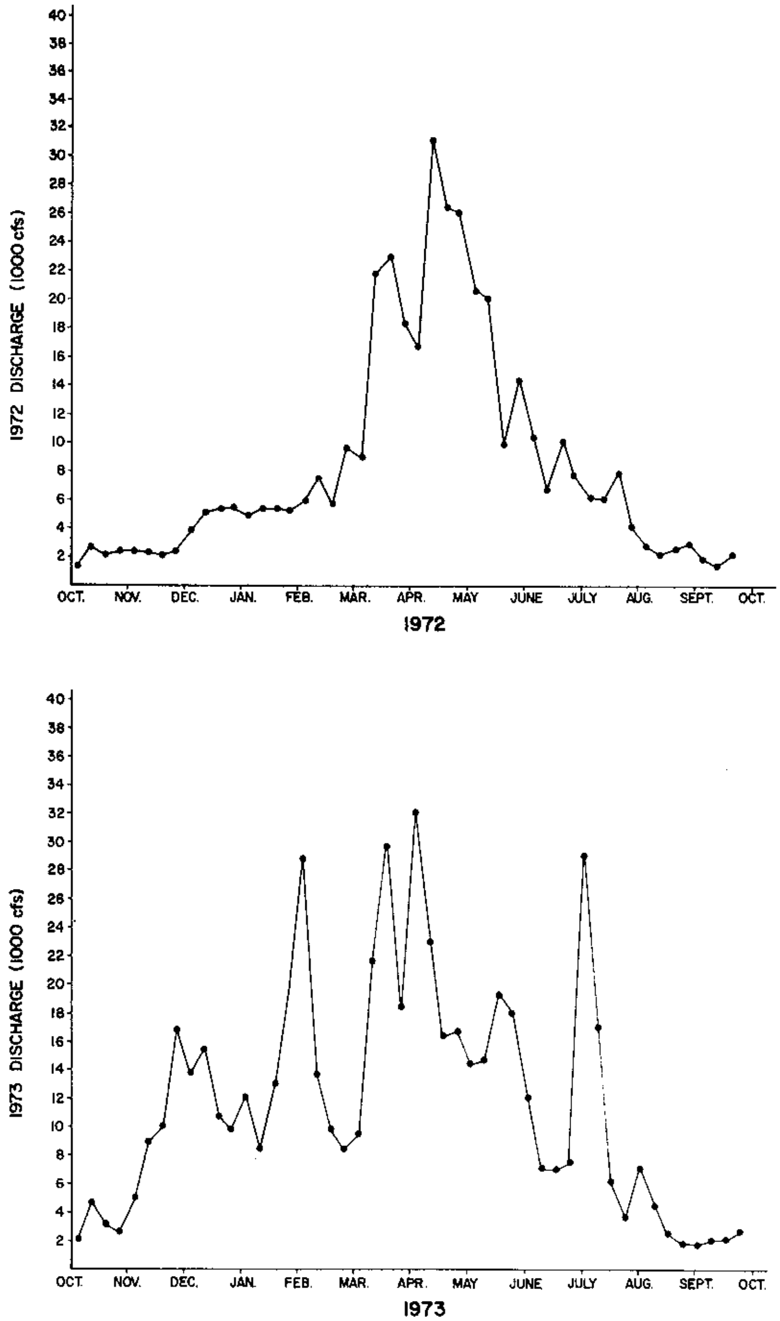


Figure B3-3
1972 and 1973 Mean Weekly Discharge
Reach 3 Merrimack River

Merrimack River Diversion Study

APPENDIX C

WATER QUALITY, MERRIMACK RIVER

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TABLE C.1

Mean Monthly Water Quality and Standard Deviation, Station 1. Base Data from U.S.G.S.*

1970 Reach #1 Station 1	pH		Temp.		Dissolved Oxygen		Dissolved Solids	
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
Oct.	6.9 (1)	-	15.5 (1)	-	5.5 (1)	-		
Nov.	6.9 (1)	-	9.8 (1)	-	7.5 (1)	-		
Dec.	7.2 (1)	-	0.9 (1)	-	12.0 (1)	-		
Jan.	7.2 (1)	-	0.1 (1)	-	13.8 (1)	-		
Feb.	7.0 (1)	-	0.2 (1)	-	13.0 (1)	-		
Mar.	7.0 (1)	-	2.0 (1)	-	13.1 (1)	-		
Apr.	7.0 (1)	-	3.1 (1)	-	13.5 (1)	-		
May	6.4 (1)	-	14.0 (1)	-	9.9 (1)	-		
Jun.	6.8 (1)	-	19.8 (1)	-	7.7 (1)	-		
Jul.	7.1 (1)	-	24.3 (1)	-	6.6 (1)	-		
Aug.	7.2 (2)	-	25.6 (2)	-	5.2 (2)	-	80 (1)	-
Sept.								
Average	7.0 (11)	0.23	10.5 (11)	9.88	9.8 (11)	3.4		

* Numbers in parentheses indicate number of elements used to obtain mean.

Fe $\bar{X}$	Fe S	Mn $\bar{X}$	Mn S	NO_3 $\bar{X}$	NO_3 S	Hardness Non Carb $\bar{X}$	Hardness Non Carb S	Acidity $\bar{X}$	Acidity S
				0.50 (1)	-				
				0.40 (1)	-				
				1.5 (1)	-				
				0.20 (1)	-				
				0.40 (1)	-				
				0.28 (1)	-				
				0.20 (1)	-				
				0.20 (1)	-				
				0.30 (1)	-				
				1.5 (1)	-				
290 (1)	-	60 (1)	-	1.35 (2)	-	23 (1)	-	3.0 (1)	-
				0.62 (11)	0.54				

SO$_4$		Cl		P		Specif. Cond.		Coliform Fecal	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
				0.20 (1)	-	130 (1)	-	410 (1)	-
				0.21 (1)	-	114 (1)		1400 (1)	-
				0.11 (1)	-	95 (1)	-	1400 (1)	-
				0.08 (1)	-	79 (1)	-	1200 (1)	-
				0.12 (1)	-	98 (1)	-	2700 (1)	-
				0.08 (1)	-	106 (1)	-	730 (1)	-
				0.06 (1)	-	65 (1)	-	300 (1)	-
				0.10 (1)	-	50 (1)	-	330 (1)	-
				0.15 (1)	-	102 (1)	-	1400 (1)	-
				0.53 (1)	-	110 (1)	-	1300 (1)	-
14 (1)	-	18 (1)	-	0.22 (2)	-	141 (2)	-	210 (2)	-
				0.17 (11)	0.13	99 (11)	27	1030 (11)	740

BOD		Oil & Grease		Phenols		Color		Turbid.	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
								4.0 (1)	-
								6.0 (1)	-
								3.0 (1)	-
								2.0 (1)	-
								4.0 (1)	-
								8.0 (1)	-
								6.0 (1)	-
								6.0 (1)	-
								1.0 (1)	-
								4.0 (1)	-
3.2 (1)	-	9.0 (1)	-	14 (1)	-	34 (1)	-	4.0 (2)	-
								4.4 (11)	2.0

N Kjeldahl $\overline{X}$	S	Methylene Blue Active Substances $\overline{X}$	S	COD $\overline{X}$	S
1.2 (1)	-	0.07 (1)	-	23 (1)	-
2.4 (1)	-	0.05 (1)	-	31 (1)	-
1.0 (1)	-	0.07 (1)	-	8.0 (1)	-
0.78 (1)	-	0.05 (1)	-	4.0 (1)	-
1.2 (1)	-	0.06 (1)	-	12 (1)	-
0.82 (1)	-	0.04 (1)	-	14 (1)	-
0.44 (1)	-	0.03 (1)	-	8.0 (1)	-
0.68 (1)	-	0.08 (1)	-	10 (1)	-
1.4 (1)	-	0.06 (1)	-	12 (1)	-
1.7 (1)	-	0.06 (1)	-	18 (1)	-
0.93 (2)	-	0.07 (2)	-	23 (2)	-
1.1 (11)	0.55	0.06 (11)	0.01	15 (11)	8.1

1971 Reach #1 Station 1	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	Dissolved Oxygen $\bar{X}$	Dissolved Oxygen S	Dissolved Solids $\bar{X}$	Dissolved Solids S
Oct.	7.1 (1)	-	17.3 (1)	-	6.7 (1)	-		
Nov.	6.5 (1)	-	9.8 (1)	-	8.0 (1)	-		
Dec.	6.6 (1)	-	1.8 (1)	-	12.3 (1)	-		
Jan.	6.7 (1)	-	0.2 (1)	-	12.4 (1)	-		
Feb.	6.7 (1)	-	0.5 (1)	-	10.6 (1)	-		
Mar.	6.7 (1)	-	1.7 (1)	-	12.6 (1)	-		
Apr.	6.5 (1)	-	3.3 (1)	-	13.1 (1)	-		
May	6.2 (1)	-	8.1 (1)	-	11.8 (1)	-		
Jun.	6.9 (1)	-	20.1 (1)	-	8.2 (1)	-		
Jul.	7.0 (1)	-	25.2 (1)	-	5.2 (1)	-		
Aug.	7.0 (1)	-	25.0 (1)	-	7.0 (1)	-		
Sept.	6.7 (1)	-	22.8 (1)	-	5.2 (1)	-	99 (1)	-
Average	6.7 (12)	0.26	11.3 (12)	10.1	9.4 (12)	3.0		

Si		Ca		Mg		K		N Ammonia	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
		8.0 (1)	-						
4.1 (1)	-	8.0 (1)	-	1.2 (1)	-	16 (1)	-	1.9 (1)	-
		8.0 (2)	-						

N Organic $\bar{X}$	N Organic S	N Total $\bar{X}$	N Total S	NO_3 $\bar{X}$	NO_3 S	NO_2 $\bar{X}$	NO_2 S	HCO_3 $\bar{X}$	HCO_3 S
				0.4 (1)	-				
				0.2 (1)	-				
				0.2 (1)	-				
				0.2 (1)	-				
				0.2 (1)	-				
				0.3 (1)	-				
				0.2 (1)	-				
				0.2 (1)	-				
				2.7 (1)	-				
1.8 (1)	-			0.2 (1)	-			26 (1)	-
0.51 (1)	-			0.1 (1)	-				
2.0 (1)	-	3.8 (1)	-	0.4 (1)	-	0.050 (1)	-	30 (1)	-
1.4 (3)	0.81			0.4 (12)	0.7			28 (2)	-

Hardness Non Carb		Alkalinity		Acidity		SO_4		Cl	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
		21 (1)	-						
25 (1)	-	25 (1)	-	3 (1)	-	14 (1)	-	0.5 (1)	-
		23 (2)							

F $\bar{X}$	F S	P $\bar{X}$	P S	Specif. Cond. $\bar{X}$	Specif. Cond. S	Coliform Fecal $\bar{X}$	Coliform Fecal S	BOD $\bar{X}$	BOD S
		0.13 (1)	-	99 (1)	-	280 (1)	-		
		0.15 (1)	-	93 (1)	-	770 (1)	-		
		0.12 (1)	-	82 (1)	-	850 (1)	-		
		0.14 (1)	-	103 (1)	-	2900 (1)	-		
		0.18 (1)	-	115 (1)	-	2000 (1)	-		
		0.10 (1)	-	113 (1)	-	820 (1)	-		
		0.12 (1)	-	76 (1)	-	640 (1)	-		
		0.05 (1)	-	54 (1)	-	900 (1)	-		
		0.10 (1)	-	104 (1)	-	680 (1)	-		
		0.21 (1)	-	143 (1)	-	530 (1)	-		
		0.18 (1)	-	108 (1)	-	226 (1)	-		
20 (1)	-	0.24 (1)	-	159 (1)	-	1000 (1)	-	6.2 (1)	-
		0.14 (12)	0.05	104 (12)	28.1	966 (12)	756		

Oil & Grease		Phenols		Color	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
5.0 (1)	-	0 (1)	-	26 (1)	-

1972 Reach #1 Station 1	pH		Temp.		Dissolved Oxygen		Dissolved Solids	
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
Oct.	7.1 (1)	-	18.5 (1)	-	6.4 (1)	-		
Nov.	6.5 (1)	-	15.0 (1)	-	5.3 (1)	-		
Dec.	6.8 (1)	-	1.0 (1)	-	7.5 (1)	-		
Jan.	6.7 (1)	-	0.7 (1)	-	14.0 (1)	-		
Feb.	6.7 (1)	-	0.0 (1)	-	14.0 (1)	-		
Mar.	6.6 (1)	-	0.0 (1)	-	14.0 (1)	-		
Apr.	6.5 (1)	-	3.5 (1)	-	13.3 (1)	-		
May	6.6 (1)	-	9.9 (1)	-	11.4 (1)	-		
Jun.	6.6 (1)	-	18.0 (1)	-	8.4 (1)	-		
Jul.	7.0 (1)	-	22.5 (1)	-	7.9 (1)	-		
Aug.	6.8 (1)	-	22.5 (1)	-	6.0 (1)	-		
Sept.	7.4 (1)	-	20.0 (1)	-	6.2 (1)	-	72 (1)	-
Average	6.8 (12)	0.27	11.0 (12)	9.40	9.5 (12)	3.5		

Fe		Mn		Ca		Mg		Na	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
320 (1)	-	60 (1)	-	7.0 (1)	-	1.1 (1)	-	12 (1)	-

K $\bar{X}$	K S	N Ammonia $\bar{X}$	N Ammonia S	NO_3 $\bar{X}$	NO_3 S	NO_2 $\bar{X}$	NO_2 S	HCO_3 $\bar{X}$	HCO_3 S
				0.40 (1)	-				
				0.30 (1)	-				
				0.31 (1)	-				
				0.20 (1)	-				
				0.30 (1)	-				
				0.30 (1)	-				
				0.20 (1)	-				
				0.09 (1)	-				
				0.60 (1)	-				
				1.40 (1)	-				
				0.50 (1)	-				
1.5 (1)	-	1.8 (1)	-	0.40 (1)	-	0.026 (1)	-	25 (1)	-
				0.42 (12)	0.34				

Hardness		Hardness Non Carb		Alkalinity		Acidity		SO_4	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
22 (1)	-	2 (1)	-	21 (1)	-	0 (1)	-	12 (1)	-

Cl		F		P		Specif. Cond.		Fecal Coliform	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
				0.19 (1)	-	125 (1)	-	350 (1)	-
				0.17 (1)	-	109 (1)	-	300 (1)	-
				0.19 (1)	-	130 (1)	-	870 (1)	-
				0.098 (1)	-	106 (1)	-	1300 (1)	-
				0.11 (1)	-	132 (1)	-	1500 (1)	-
				0.10 (1)	-	112 (1)	-	330 (1)	-
				0.50 (1)	-	84 (1)	-	47 (1)	-
				0.055 (1)	-	59 (1)	-	1300 (1)	-
				0.089 (1)	-	85 (1)	-	600 (1)	-
				0.11 (1)	-	94 (1)	-	990 (1)	-
				0.12 (1)	-	108 (1)	-	7600 (1)	-
17 (1)	-	0.3 (1)	-	0.19 (1)	-	131 (1)	-	330 (1)	-
				0.16 (12)	0.12	106 (12)	22.5	1290 (12)	2040

CO_2		BOD		Oil & Grease		Phenols		Color	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
1.6 (1)	-	3.4 (1)	-	10 (1)	-	9 (1)	-	25 (1)	-

Turbid.		N Kjeldahl		Chlorophyll A		Methylene Blue Active Substances		COD	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
3 (1)	-	2.5 (1)	-	15 (1)	-	0.06 (1)	-	21 (1)	-
3 (1)	-	1.5 (1)	-	2.4 (1)	-	0.05 (1)	-	14 (1)	-
13 (1)	-	1.2 (1)	-	2.9 (1)	-	0.06 (1)	-	15 (1)	-
8 (1)	-	0.9 (1)	-	0.31 (1)	-	0.05 (1)	-	15 (1)	-
6 (1)	-	1.2 (1)	-	3.8 (1)	-	0.05 (1)	-	16 (1)	-
10 (1)	-	0.7 (1)	-	5.0 (1)	-	0.03 (1)	-	11 (1)	-
3 (1)	-	0.52 (1)	-	1.2 (1)	-	0.03 (1)	-	12 (1)	-
7 (1)	-	0.39 (1)	-	1.5 (1)	-	0.02 (1)	-	11 (1)	-
5 (1)	-	1.0 (1)	-	2.6 (1)	-	0.04 (1)	-	11 (1)	-
3 (1)	-	1.0 (1)	-	6.6 (1)	-	0.04 (1)	-	16 (1)	-
4 (1)	-	1.5 (1)	-	12.0 (1)	-	0.04 (1)	-	13 (1)	-
4 (1)	-	2.2 (1)	-	20.0 (1)	-	0.05 (1)	-	14 (1)	-
6 (12)	3	1.2 (12)	0.63	6.1 (12)	6.2	0.04 (12)	0.01	14 (12)	2.9

Turbid.		N Kjeldahl		Chlorophyll A		Methylene Blue Active Substances		COD	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
3 (1)	-	2.5 (1)	-	7.8 (1)	-	0.06 (1)	-	13 (1)	-
1 (1)	-	1.4 (1)	-	1.6 (1)	-	0.10 (1)	-	15 (1)	-
2 (1)	-	0.98 (1)	-	0.0 (1)	-	0.04 (1)	-	14 (1)	-
2 (1)	-	1.5 (1)	-	0.9 (1)	-	0.04 (1)	-	8 (1)	-
1 (1)	-	1.5 (1)	-	0.2 (1)	-	0.04 (1)	-	14 (1)	-
5 (1)	-	0.42 (1)	-	0.0 (1)	-	0.05 (1)	-	10 (1)	-
30 (1)	-	0.78 (1)	-	2.7 (1)	-	0.04 (1)	-	19 (1)	-
2 (1)	-	0.55 (1)	-	2.6 (1)	-	0.02 (1)	-	12 (1)	-
1 (1)	-	1.4 (1)	-	11 (1)	-	0.07 (1)	-	12 (1)	-
9 (1)	-	3.4 (1)	-	24 (1)	-	0.05 (1)	-	22 (1)	-
8 (1)	-	1.4 (1)	-	27 (1)	-	0.05 (1)	-	21 (1)	-
7 (1)	-	3.4 (1)	-	24 (1)	-	0.07 (1)	-	24 (1)	-
6 (12)	8	1.6 (12)	1.0	8.5 (12)	10.5	0.05 (12)	0.02	15 (12)	5.0

1973 Reach #1 Station 1	COD		pH		Temp.		Dissolved Oxygen	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
Oct.	14 (1)	-	7.2 (1)	-	16 (1)	-	5.4 (1)	-
Nov.	12 (1)	-	6.7 (1)	-	8 (1)	-	9.5 (1)	-
Dec.	12 (1)	-	7.3 (1)	-	1 (1)	-		
Jan.	10 (1)	-	7.2 (1)	-	0 (3)	0.6	12.7 (1)	-
Feb.	13 (1)	-	6.7 (1)	-	1 (4)	0.6	13.8 (1)	-
Mar.	10 (1)	-	6.8 (1)	-	3 (4)	2	13.1 (1)	-
Apr.	9 (1)	-	6.4 (1)	-	8 (4)	4	12.8 (1)	-
May	10 (1)	-	6.6 (1)	-	13 (4)	0.82	9.9 (1)	-
Jun.	19 (1)	-	7.0 (1)	-	21 (4)	2.5	7.7 (1)	-
Jul.			6.3 (1)	-	23 (4)	1.6	8.4 (1)	-
Aug.			7.1 (1)	-	25 (4)	0.96	5.5 (1)	-
Sept.			6.8 (1)	-	21 (4)	4.5	5.2 (2)	-
Average	12 (9)	3.1	6.8 (12)	0.32	12 (12)	9.4	9.5 (11)	3.3

Dissolved Solids		Si		Ca		Mg		Na	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
57 (1)	-	6.3 (1)	-	6.0 (1)	-	0.9 (1)	-	9.2 (1)	-
45 (1)	-	6.0 (1)	-	4.5 (1)	-	0.8 (1)	-	7.2 (1)	-
55 (1)	-	6.3	-	5.5	-	0.9	-	9.5	-
33 (1)	-	4.7 (1)	-	3.7 (1)	-	0.6 (1)	-	4.7 (1)	-
34 (1)	-	4.6 (1)	-	4.3 (1)	-	0.6 (1)	-	4.9 (1)	-
50 (1)	-	4.9 (1)	-	5.2 (1)	-	0.9 (1)	-	8.7 (1)	-
27 (1)	-	4.6 (1)	-	3.2 (1)	-	0.6 (1)	-	3.8 (1)	-
71 (1)	-	5.0 (1)	-	6.9 (1)	-	1.2 (1)	-	15 (1)	-
59 (1)	-	4.6 (1)	-	6.5 (1)	-	1.3 (1)	-	13 (1)	-
48 (9)	14	5.2 (9)	0.75	5.1 (9)	1.3	0.9 (9)	0.3	8.4 (9)	3.8

K		N Ammonia		N Organic		N Total		NO_2	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
1.1 (1)	-	0.65 (1)	-	1.1 (1)	-			0.0 (1)	-
0.7 (1)	-	0.30 (1)	-	1.8 (1)	-			0.07 (1)	-
0.9	-	0.46	-	0.72	-			0.01 (1)	-
0.6 (1)	-	0.28 (1)	-	0.28 (1)	-			0.0 (1)	-
0.7 (1)	-	0.29 (1)	-	0.17 (1)	-			0.0 (1)	-
1.1 (1)	-			0.10 (1)	-			0.0 (1)	-
0.2 (1)	-	0.0 (1)	-			3.4 (1)	-	0.0 (1)	-
		0.1 (1)	-					0.0 (1)	-
1.7 (1)	-			0.0 (1)	-				
0.9 (8)	0.4	0.3 (7)	0.2	0.6 (7)	0.7			0.0 (8)	0.0

NO_3		HCO_3		CO_3		Hardness		Hardness Non Carb	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
3.0 (1)	-								
0.9 (1)	-								
0.9 (1)	-								
1.3 (1)	-	14 (1)	-	0 (1)	-	19 (1)	-	7 (1)	-
1.3 (1)	-	8 (1)	-	0 (1)	-	15 (1)	-	8 (1)	-
1.3 (1)	-	11 (1)	-	0 (1)	-	17 (1)	-	8 (1)	-
0.9 (1)	-	5 (1)	-	0 (1)	-	12 (1)	-	8 (1)	-
0.9 (1)	-	6 (1)	-	0 (1)	-	13 (1)	-	8 (1)	-
4.2 (1)	-	8 (1)	-	0 (1)	-	17 (1)	-	10 (1)	-
1.2 (1)	-	5 (1)	-	0 (1)	-	10 (1)	-	6 (1)	-
9.7 (1)	-	9 (1)	-	0 (1)	-	22 (1)	-	15 (1)	-
		9 (1)	-	0 (1)	-	22 (1)	-	14 (1)	-
2.3 (11)	2.7	8 (9)	3	0 (9)	-	16 (9)	4.2	9 (9)	3

Alkalinity		SO_4		Cl		F		P	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
								0.19 (1)	-
								0.12 (1)	-
								0.05 (1)	-
11 (1)	-	11.0 (1)	-	13 (1)	-	0.1 (1)	-	0.09 (1)	-
7 (1)	-	9.0 (1)	-	11 (1)	-	0.1 (1)	-	0.07 (1)	-
9 (1)	-	9.2 (1)	-	15 (1)	-	0.3 (1)	-	0.08 (1)	-
4 (1)	-	8.0 (1)	-	6 (1)	-	0.8 (1)	-	0.04 (1)	-
5 (1)	-	8.5 (1)	-	6 (1)	-	0.4 (1)	-	0.05 (1)	-
7 (1)	-	8.5 (1)	-	12 (1)	-	0.2 (1)	-	0.07 (1)	-
4 (1)	-	5.5 (1)	-	5.0 (1)	-	0.3 (1)	-	0.08 (1)	-
7 (1)	-	9.2 (1)	-	19 (1)	-	0.3 (1)	-	0.18 (1)	-
7 (1)	-	9.7 (1)	-	17 (1)	-	0.3 (1)	-	0.17 (1)	-
7 (9)	2	8.0 (9)	2.7	12 (9)	5.1	0.3 (9)	0.2	0.10 (12)	0.05

Specif. Cond.		Fecal Coliform		CO_2		Turbid.		N Kjeldahl	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
150 (1)	-	400 (1)	-			3 (1)	-	2.5 (1)	-
98 (1)	-	780 (1)	-			3 (1)	-	1.3 (1)	-
80 (1)	-	2400 (1)	-			3 (1)	-	0.66 (1)	-
88 (3)	11	530 (1)	-	1.4 (1)	-	2 (1)	-	0.80 (1)	-
91 (4)	6.3	300 (1)	-	2.6 (1)	-	3 (1)	-	0.77 (1)	-
72 (4)	18	250 (1)	-	2.8 (1)	-	1 (1)	-	0.78 (1)	-
126 (4)	145	540 (1)	-	3.2 (1)	-	4 (1)	-	0.37 (1)	-
161 (4)	141	640 (1)	-	2.4 (1)	-	4 (1)	-	0.46 (1)	-
84 (4)	7.8	600 (1)	-	1.3 (1)	-	3 (1)	-	0.84 (1)	-
78 (4)	28	1100 (1)	-	4.0 (1)	-			0.2 (1)	-
155 (4)	97.7	900 (1)	-	1.1 (1)	-				
127 (4)	10.5	1300 (1)	-	2.3 (1)	-			1.4 (1)	-
109 (12)	32.8	812 (12)	590	2.3 (9)	0.95	3 (9)	0.9	0.92 (11)	0.64

Chlorophyll A		Methylene		PO_4	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
8.2 (1)	-	0.04 (1)	-	0.58 (1)	-
1.4 (1)	-	0.06 (1)	-	0.37 (1)	-
0.8 (1)	-	0.03 (1)	-		
0.0 (1)	-	0.03 (1)	-		
0.4 (1)	-	0.04 (1)	-		
1.5 (1)	-	0.04 (1)	-		
0.7 (1)	-	0.03 (1)	-		
1.9 (1)	-	0.02 (1)	-		
4.4 (1)	-	0.04 (1)	-		
2.1 (9)	2.6	0.04 (9)	0.01	0.48 (2)	-

TABLE C.2

Mean Monthly Water Quality and Standard Deviation, Station 2. Base Data from U.S.G.S.*

1968 Reach #1 Station 2	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	Dissolved Solids $\bar{X}$	Dissolved Solids S	Si $\bar{X}$	Si S
Oct.	-	-	15 (4)	2.6				
Nov.	6.3 (2)	-	2 (2)	-				
Dec.	6.5 (4)	0.10	1 (4)	0				
Jan.	6.5 (4)	0.17	1 (4)	1	123 (1)	-	8.1 (1)	-
Feb.	6.5 (3)	0.12	1 (4)	1	68 (1)	-	7.1 (1)	-
Mar.	6.5 (4)	0.15	1 (4)	1	36 (1)	-	4.9 (1)	-
Apr.	-	-	9 (4)	3				
May	-	-	15 (4)	1.3				
Jun.	6.4 (1)	-	18 (4)	1.3	55 (1)	-	5.1	-
Jul.	7.1 (4)	0.29	26 (4)	2.1				
Aug.	6.8 (4)	0.19	24 (4)	0.50				
Sept.	6.7 (3)	0.45	22 (4)	0.82				
Average	6.6 (29)	0.30	12 (44)	10	71 (4)	37	6.3 (4)	1.6

* Numbers in parentheses indicate number of elements used to obtain mean.

Fe		Mn		Ca		Mg		Na	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
0.46 (1)	-	0.16 (1)	-	10 (1)	-	2.2 (1)	-	24 (1)	-
0.18 (1)	-	0.10 (1)	-	5.6 (1)	-	1.1 (1)	-	9.1 (1)	-
0.13 (1)	-	0.05 (1)	-	3.1 (1)	-	0.6 (1)	-	4.5 (1)	-
0.39 (1)	-	0.03 (1)	-	4.7 (1)	-	0.8 (1)	-	7.1 (1)	-
0.29 (4)	0.16	0.09 (4)	0.06	5.9 (4)	3.0	1.2 (4)	0.71	11 (4)	8.8

K		NO_2		HCO_3		CO_3		Hardness	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
2.2 (1)	-	10 (1)	-	0 (1)	-	34 (1)	-	26 (1)	-
1.1 (1)	-	6 (1)	-	0 (1)	-	18 (1)	-	14 (1)	-
1.0 (1)	-	4 (1)	-	0 (1)	-	10 (1)	-	7 (1)	-
0.7 (1)	-	10 (1)	-	0 (1)	-	14 (1)	-	6 (1)	-
1.3 (4)	0.66	8 (4)	3	0 (4)	0	19 (4)	11	13 (4)	9

SO_4		Cl		F		Specif. Cond.		NO_3	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
						113 (4)	9.31		
						115 (2)			
						86 (4)	18		
21 (1)	-	37 (1)	-	0.3 (1)	-	114 (1)	12.4	6.4 (1)	-
12 (1)	-	14 (1)	-	0.2 (1)	-	112 (4)	3.37	2.5 (1)	-
9.2 (1)	-	8 (1)	-	0.1 (1)	-	92 (4)	34	0.3 (1)	-
						70 (4)	10		
						69 (4)	13		
4.7 (1)	-	11 (1)	-	0.0 (1)	-	72 (4)	5.8	0.4 (1)	-
						98 (4)	21		
						128 (4)	3.86		
						132 (4)	4.03		
12 (4)	6.9	18 (4)	13	0.2 (4)	0.1	99 (43)	25	2.4 (4)	2.9

Color		PO_4		Dissolved Oxygen	
$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
				5.1 (4)	0.37
				12.3 (2)	
				13.3 (4)	0.88
19 (1)	-	0.17 (1)	-	12.4 (4)	0.59
20 (1)	-	0.19 (1)	-	11.4 (4)	0.51
-	-	0.02 (1)	-	11.3 (4)	1.07
				9.8 (4)	1.1
				8.7 (2)	
17 (1)	-	-	-	-	-
				7.1 (2)	
				6.6 (4)	0.87
				4.8 (4)	1.0
19 (3)	1.5	0.13 (3)	0.09	9.3 (38)	3.1

1969 Reach #1 Station 2	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	Dissolved Oxygen $\bar{X}$	Dissolved Oxygen S	Dissolved Solids $\bar{X}$	Dissolved Solids S
Oct.	6.9 (2)		16.3 (4)	2.24	5.1 (4)	0.51		
Nov.	6.9 (4)	0.0	5.9 (4)	3.0	9.8 (4)	2.6		
Dec.	6.6 (4)	0.08	1.3 (4)	1.0	13.2 (4)	0.35		
Jan.	6.5 (4)	0.05	0.5 (4)	0.4	12.3 (4)	0.73	75 (1)	-
Feb.	6.6 (4)	0.12	0.5 (4)	0.5	12.5 (4)	0.19		
Mar.	6.6 (4)	0.08	1.6 (4)	0.62	12.8 (3)	0.25		
Apr.	6.5 (4)	0.10	5.6 (4)	2.0	11.6 (2)		16 (1)	-
May	6.6 (3)	0.06	12.9 (4)	2.95	10.0 (4)	0.98		
Jun.	7.0 (4)	0.08	21.8 (4)	1.27	8.6 (3)	1.9		
Jul.	-	-	24.8 (3)	1.31	6.7 (2)			
Aug.	6.4 (2)		24.5 (4)	0.94	6.2 (3)	0.10		
Sept.	6.7 (2)		22.1 (3)	2.86	6.8 (3)	0.87		
Average	6.7 (37)	0.21	10.9 (46)	9.66	9.8 (40)	3.0	61 (2)	-

Si		Fe		Mn		Ca		Mg	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
6.6 (1)	-	160 (1)	-	100 (1)	-	5.4 (1)	-	0.8 (1)	-
4.0 (1)	-	160 (1)	-	30 (1)	-	3.3 (1)	-	0.4 (1)	-
5.3 (2)	-	160 (2)	-	115 (2)	-	4.4 (2)	-	0.6 (2)	-

Na		K		NO_3		HCO_3		CO_3	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
9.1 (1)	-	1.1 (1)	-	2.2 (1)	-	6 (1)	-	0 (1)	-
3.9 (1)	-	0.5 (1)	-	0.0 (1)	-	6 (1)	-	0 (1)	-
6.5 (2)	-	0.8 (2)	-	1.1 (2)	-	6 (2)	-	0 (2)	-

Hardness		Hardness Non Carb		SO_4		Cl		F	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
12 (1)	-	16 (1)	-	12 (1)	-	14 (1)	-	0.2 (1)	-
4 (1)	-	10 (1)	-	8.1 (1)	-	6.0 (1)	-	0.0 (1)	-
8 (2)	-	13 (2)		10 (2)		10 (2)		0.1 (2)	

Specific Conduct.		Color		PO_4	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
125 (4)	4.43				
112 (4)	9.93				
84 (4)	10				
105 (4)	3.30	-	-	-	-
111 (4)	8.50				
98 (4)	11				
55 (4)	8.3	21 (1)	-	0.07 (1)	-
63 (4)	7.1				
92 (4)	7.6				
107 (3)	10.4				
84 (4)	8.1				
112 (3)	4.04				
95 (46)	22	21 (1)	-	0.07 (1)	-

1970 Reach #1 Station 2	Temp. $\overline{X}$	Temp. S	Specific Conduct. $\overline{X}$	Specific Conduct. S
Oct.	15 (4)	3.3	134 (4)	5.32
Nov.	7 (4)	3	81 (4)	22
Dec.	2 (3)	1	82 (3)	18
Jan.	0.0 (2)	-	94 (2)	-
Feb.	0.5 (1)	-	105 (1)	-
Mar.	2.5 (4)	0.58	100 (4)	12.6
Apr.	4 (4)	2	57 (4)	8.1
May	16 (4)	2	69 (4)	7.6
Jun.	22 (4)	1.4	109 (4)	15.6
Jul.	25 (4)	2.1	138 (4)	29.5
Aug.	26 (4)	1.4	164 (4)	20.0
Sept.	22 (2)	-	142 (2)	-
Average	13 (40)	9.7	106 (40)	36.1

1971 Reach #1 Station 2	Temp.		Specific Conduct.	
	$\overline{X}$	S	$\overline{X}$	S
Oct.	15 (4)	2.5	108 (4)	11.7
Nov.	8 (4)	2	98 (4)	11
Dec.	2 (4)	2	85 (1)	-
Jan.	0 (4)	0	-	-
Feb.	1 (4)	1	124 (4)	8.46
Mar.	2 (4)	1	109 (4)	3.83
Apr.	6 (4)	3	68 (4)	15
May	13 (4)	3.2	64 (4)	9.1
Jun.	23 (4)	3.4	113 (4)	17.5
Jul.	26 (4)	0.51	135 (4)	8.34
Aug.	25 (4)	1.4	123 (4)	16.1
Sept.	22 (4)	2.4	123 (4)	11.9
Average	12 (48)	9.9	106 (41)	25.1

1972 Reach #1 Station 2	Temp. $\bar{X}$	Temp. S	Specific Conduct. $\bar{X}$	Specific Conduct. S
Oct.	16 (4)	1.9	123 (4)	11.7
Nov.	8 (4)	5	120 (4)	7.23
Dec.	1 (4)	1	119 (4)	6.85
Jan.	1 (4)	1	116 (4)	7.80
Feb.	0 (4)	0	118 (4)	14.9
Mar.	1 (4)	0	104 (4)	22.2
Apr.	5 (4)	2	71 (4)	11
May	13 (4)	4.4	65 (3)	4.0
Jun.	20 (3)	1.0	- (4)	-
Jul.	26 (2)	-	91 (2)	-
Aug.	24 (4)	1.3	122 (4)	14.4
Sept.	20 (4)	1.3	127 (4)	12.7
Average	10 (45)	9.3	109 (41)	22.9

TABLE C.3

Mean Monthly Water Quality and Standard Deviation, Station 3.
Base Data from U.S.G.S.*

1968 Reach #2 Station 3	Sediment Discharge $\bar{X}$	Sediment Discharge S	Sediment Concent. $\bar{X}$	Sediment Concent. S	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S
Oct.	230 (4)	24.5	30 (4)	2.8				
Nov.	100 (4)	33	11 (4)	3.8	6.1 (1)	-	2 (1)	-
Dec.	390 (4)	266	19 (4)	11				
Jan.	80 (4)	37	5 (3)	2	5.9 (1)	-	1 (1)	-
Feb.	75 (4)	33	5 (4)	1	6.2 (1)	-	0 (1)	-
Mar.	5100 (4)	6900	54 (4)	68	5.9 (1)	-	-	-
Apr.	1090 (4)	839	24 (4)	13	6.0 (1)	-	12 (1)	-
May	518 (4)	415	16 (4)	5.8	6.0 (1)	-	-	-
Jun.	593 (4)	415	11 (4)	3.7				
Jul.	285 (4)	378	-	-				
Aug.	45 (4)	13	8 (2)	-				
Sept.	25 (4)	5.8	6 (4)	0.5				
Average	710 (48)	2200	18 (41)	24	6.0 (6)	0.12	4 (4)	6

* Numbers in parentheses indicate number of elements used to obtain mean.

Dissolved Solids $\overline{X}$	S	Si $\overline{X}$	S	Fe $\overline{X}$	S	Mn $\overline{X}$	S	Ca $\overline{X}$	S
74 (1)	-	5.8 (1)	-	-	-	-	-	5.3 (1)	-
66 (1)	-	7.2 (1)	-	0.14 (1)	-	0.12 (1)	-	5.9 (1)	-
73 (1)	-	7.1 (1)	-	0.28 (1)	-	0.11 (1)	-	6.8 (1)	-
36 (1)	-	5.0 (1)	-	0.09 (1)	-	0.07 (1)	-	3.1 (1)	-
44 (1)	-	4.1 (1)	-	-	-	-	-	5.4 (1)	-
44 (1)	-	4.1 (1)	-	0.38 (1)	-	0.02 (1)	-	3.9 (1)	-
56 (6)	17	5.6 (6)	1.4	0.22 (4)	0.13	0.08 (4)	0.05	5.1 (6)	1.4

Mg $\bar{X}$	Mg S	Na $\bar{X}$	Na S	K $\bar{X}$	K S	HCO_3 $\bar{X}$	HCO_3 S	CO_3 $\bar{X}$	CO_3 S
0.9 (1)	-	11 (1)	-	1.2 (1)	-	5 (1)	-	0 (1)	-
1.1 (1)	-	12 (1)	-	1.2 (1)	-	6 (1)	-	0 (1)	-
1.1 (1)	-	10 (1)	-	1.1 (1)	-	14 (1)	-	0 (1)	-
0.6 (1)	-	4.5 (1)	-	1.0 (1)	-	4 (1)	-	0 (1)	-
0.6 (1)	-	5.1 (1)	-	1.0 (1)	-	6 (1)	-	0 (1)	-
0.7 (1)	-	5.5 (1)	-	0.6 (1)	-	7 (1)	-	0 (1)	-
0.8 (6)	0.2	8.0 (6)	3.3	1.0 (6)	0.22	7 (6)	4	0 (6)	0

Hardness		Hardness Non Carb		SO_4		Cl		F	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
16 (1)	-	12 (1)	-	13 (1)	-	17 (1)	-	0.3 (1)	-
19 (1)	-	14 (1)	-	14 (1)	-	17 (1)	-	0.2 (1)	-
22 (1)	-	10 (1)	-	13 (1)	-	16 (1)	-	0.1 (1)	-
10 (1)	-	7 (1)	-	9.4 (1)	-	7.8 (1)	-	0.2 (1)	-
16 (1)	-	11 (1)	-	8.8 (1)	-	8.1 (1)	-	0.2 (1)	-
12 (1)	-	7 (1)	-	8.8 (1)	-	7.2 (1)	-	0.2 (1)	-
16 (6)	4.4	10 (6)	2.8	11 (6)	2.4	12 (6)	4.9	0.2 (6)	0.1

Specific Conduct.		NO_3		Color		PO_4	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
108 (1)	-	3.4 (1)	-	17 (1)	-	0.48 (1)	-
105 (1)	-	2.9 (1)	-	19 (1)	-	0.84 (1)	-
107 (1)	-	0.8 (1)	-	20 (1)	-	0.13 (1)	-
55 (1)	-	0.5 (1)	-	-	-	0.02 (1)	-
59 (1)	-	4.6 (1)	-	-	-	0.05 (1)	-
61 (1)	-	0.7 (1)	-	7 (1)	-	0.27 (1)	-
83 (6)	27	2.2 (6)	1.7	16 (4)	6.0	0.30 (6)	0.31

1969 Reach #2 Station 3	Sediment Discharge $\bar{X}$	S	Sediment Concent. $\bar{X}$	S	pH $\bar{X}$	S	Temp. $\bar{X}$	S
Oct.	36 (4)	7.2	7 (4)	0.8	6.4 (1)	-	13 (1)	-
Nov.	120 (4)	72	9 (4)	2				
Dec.	300 (4)	260	10 (4)	7.2	6.2 (1)	-	4 (1)	-
Jan.	110 (4)	130	7 (4)	7	6.1 (1)	-	1 (1)	-
Feb.	150 (4)	63.5	10 (4)	2.9				
Mar.	870 (4)	1600	16 (4)	20	6.3 (1)	-	-	-
Apr.	6955 (4)	4122	70 (4)	36	6.3 (1)	-	5 (1)	-
May	1068 (4)	874	25 (4)	9.2				
Jun.	157 (4)	43.4	12 (4)	1.3				
Jul.	140 (4)	180	10 (4)	2.8	6.2 (1)	-	24 (1)	-
Aug.	300 (4)	430	13 (4)	10	6.7 (1)	-	26 (1)	-
Sept.	46 (4)	29	6 (4)	1	6.3 (1)	-	21 (1)	-
Average	850 (48)	2200	16 (48)	21	6.3 (8)	0.18	13 (7)	10

Dissolved Solids		Si		Fe		Mn		Ca	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
102 (1)	-	3.2 (1)	-	240 (1)	-	140 (1)	-	9.5 (1)	-
104 (1)	-	6.6 (1)	-	360 (1)	-	190 (1)	-	9.6 (1)	-
111 (1)	-	8.4 (1)	-	220 (1)	-	190 (1)	-	11 (1)	-
65 (1)	-	5.6 (1)	-	130 (1)	-	0 (1)	-	5.8 (1)	-
30 (1)	-	4.1 (1)	-	20 (1)	-	30 (1)	-	3.2 (1)	-
59 (1)	-	0.1 (1)	-	220 (1)	-	0 (1)	-	6.0 (1)	-
63 (1)	-	5.2 (1)	-	340 (1)	-	30 (1)	-	6.5 (1)	-
70 (1)	-	5.2 (1)	-	430 (1)	-	60 (1)	-	6.4 (1)	-
75 (8)	28	4.8 (8)	2.5	245 (8)	132	80 (8)	81	7.3 (8)	2.6

Mg		Na		K		NO_3		HCO_3	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
1.9 (1)	-	19 (1)	-	2.4 (1)	-	4.7 (1)	-	17 (1)	-
1.7 (1)	-	15 (1)	-	2.2 (1)	-	3.6 (1)	-	9 (1)	-
2.1 (1)	-	24 (1)	-	2.2 (1)	-	6.5 (1)	-	10 (1)	-
1.1 (1)	-	12 (1)	-	1.1 (1)	-	4.4 (1)	-	8 (1)	-
0.4 (1)	-	3.8 (1)	-	0.5 (1)	-	0.8 (1)	-	4 (1)	-
0.9 (1)	-	10 (1)	-	1.0 (1)	-	6.6 (1)	-	7 (1)	-
0.6 (1)	-	8 (1)	-	0.9 (1)	-	1.6 (1)	-	14 (1)	-
1.3 (1)	-	11 (1)	-	1.2 (1)	-	2.0 (1)	-	16 (1)	-
1.3 (8)	0.61	13 (8)	6.4	1.4 (8)	0.72	3.8 (8)	2.2	11 (8)	4.6

CO_3		Hardness		Hardness Non Carb		SO_4		Cl	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
0 (1)	-	32 (1)	-	18 (1)	-	18 (1)	-	30 (1)	-
0 (1)	-	31 (1)	-	24 (1)	-	23 (1)	-	24 (1)	-
0 (1)	-	36 (1)	-	28 (1)	-	23 (1)	-	38 (1)	-
0 (1)	-	19 (1)	-	12 (1)	-	12 (1)	-	18 (1)	-
0 (1)	-	10 (1)	-	6 (1)	-	8 (1)	-	5 (1)	-
0 (1)	-	18 (1)	-	13 (1)	-	13 (1)	-	15 (1)	-
0 (1)	-	18 (1)	-	7 (1)	-	11 (1)	-	11 (1)	-
0 (1)	-	22 (1)	-	8 (1)	-	13 (1)	-	17 (1)	-
0 (8)	0	23 (8)	8.9	15 (8)	8.1	15 (8)	5.6	20 (8)	11

F		Specific Conduct.		Color		PO_4	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
0.1 (1)	-	174 (1)	-	26 (1)	-	1.3 (1)	-
0.2 (1)	-	160 (1)	-	-	-	0.89 (1)	-
0.2 (1)	-	218 (1)	-	-	-	1.7 (1)	-
0.1 (1)	-	112 (1)	-	14 (1)	-	0.28 (1)	-
0 (1)	-	46 (1)	-	38 (1)	-	-	-
0.2 (1)	-	104 (1)	-	33 (1)	-	-	-
0.2 (1)	-	8.7 (1)	-	-	-	-	-
0.1 (1)	-	117 (1)	-	28 (1)	-	0.27 (1)	-
0.1 (8)	0.1	117 (8)	67.9	28 (5)	9.0	0.90 (5)	0.63

1970 Reach #2 Station 3	Sediment Discharge $\overline{X}$	Sediment Discharge S	Sediment Concent. $\overline{X}$	Sediment Concent. S	pH $\overline{X}$	pH S	Temp. $\overline{X}$	Temp. S
Oct.	23 (4)	10	4 (4)	1	6.9 (1)	-	16 (1)	-
Nov.	812 (4)	996	20 (4)	16	6.8 (1)	-	10 (1)	-
Dec.	980 (4)	1300	18 (4)	17	7.1 (1)	-	1 (1)	-
Jan.	175 (4)	85.7	7 (4)	1	7.3 (1)	-	.1 (1)	-
Feb.	3350 (4)	4720	41 (4)	46	7.1 (1)	-	1 (1)	-
Mar.	578 (4)	778	15 (4)	12	7.0 (1)	-	2 (1)	-
Apr.	2624 (4)	935.8	38 (4)	9.6				
May	739 (4)	567	20 (4)	11	6.6 (1)	-	14 (1)	-
Jun.	120 (4)	24	13 (4)	5.8	6.8 (1)	-	19 (1)	-
Jul.	72 (4)	26	12 (4)	1	7.1 (1)	-	25 (1)	-
Aug.	33 (4)	16	7 (4)	2	7.2 (2)	-	26 (2)	-
Sept.	43 (4)	7.3	10 (4)	1				
Average	800 (48)	1700	17 (48)	18	7.0 (10)	0.21	11 (10)	10

Dissolved Oxygen		Dissolved Solids		Si		Fe		Mn	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
5.8 (1)	-								
8.7 (1)	-								
11.2 (1)	-	68 (1)	-	6.5 (1)	-	420 (1)	-	10 (1)	-
14.5 (1)	-								
13.4 (1)	-								
		67 (1)	-	6.2 (1)	-				
10.3 (1)	-								
7.4 (1)	-	71 (1)	-	4.9 (1)	-	0 (1)	-	0 (1)	-
6.7 (1)	-								
6.5 (2)	-	95 (1)	-	1.8 (1)	-				
9.4 (9)	3.2	75 (4)	13	4.9 (4)	2.2	210 (2)	-	5 (2)	-

Ca $\bar{X}$	Ca S	Mg $\bar{X}$	Mg S	Na $\bar{X}$	Na S	K $\bar{X}$	K S	N Ammonia $\bar{X}$	N Ammonia S
5.8 (1)	-	1.1 (1)	-	10 (1)	-	1.2 (1)	-	0.20 (1)	-
5.8 (1)	-	1.0 (1)	-	11 (1)	-	9 (1)	-	0.75 (1)	-
6.5 (1)	-	1.0 (1)	-	10 (1)	-	1.1 (1)	-	0.55 (1)	-
7.5 (1)	-	1.3 (1)	-	16 (1)	-	1.6 (1)	-	0.21 (1)	-
6.4 (4)	0.80	1.1 (4)	0.14	12 (4)	2.9	3.2 (4)	3.9	0.43 (4)	0.27

NO_3		HCO_3		Hardness		Hardness Non Carb		SO_4	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
1.6 (1)	-	8 (1)	-	19 (1)	-	12 (1)	-	14 (1)	-
1.4 (1)	-	14 (1)	-	18 (1)	-	7 (1)	-	12 (1)	-
3.0 (1)	-	16 (1)	-	20 (1)	-	7 (1)	-	12 (1)	-
9.8 (1)	-	14 (1)	-	24 (1)	-	12 (1)	-	14 (1)	-
4.0 (4)	4.0	13 (4)	3.5	20 (4)	2.6	10 (4)	2.9	13 (4)	1.2

Cl		F		P		Specific Conduct.		Fecal Coliform	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
						142 (1)	-	10,000 (1)	-
						120 (1)	-	3300 (1)	-
17 (1)	-	0.1 (1)	-	0.42 (1)	-	109 (1)	-	4800 (1)	-
						90 (1)	-	2600 (1)	-
						80 (1)	-	1400 (1)	-
18 (1)	-	0.1 (1)	-	0.38 (1)	-	110 (1)	-	1400 (1)	-
								1100 (1)	-
						56 (1)	-	850 (1)	-
12 (1)	-	0.2 (1)	-	0.46 (1)	-	112 (1)	-	3600 (1)	-
						118 (1)	-	1400 (1)	-
21 (1)	-	0.2 (1)	-	0.04 (1)	-	146 (2)	-	3300 (2)	-
17 (4)	3.7	0.2 (4)	0.1	0.33 (4)	0.19	108 (10)	27.2	3070 (11)	2620

BOD	
$\bar{X}$	S
2.6 (1)	-
2.3 (1)	-
2.3 (1)	-
2.0 (1)	-
1.8 (1)	-
2.6 (1)	-
1.4 (1)	-
1.9 (1)	-
2.6 (1)	-
7.1 (1)	-
4.2 (2)	-
2.8 (11)	1.6

1971 Reach #2 Station 3	Sediment Discharge		Sediment Concent.		pH		Dissolved Solids	
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
Oct.	65 (4)	6.9	8 (4)	3				
Nov.	26 (4)	6.2	2 (4)	1				
Dec.	97 (4)	51	7 (4)	4	6.5 (1)	-	54 (1)	-
Jan.	38 (4)	9.8	3 (4)	1				
Feb.	62 (4)	39	4 (4)	2				
Mar.	303 (4)	97.7	11 (4)	2	6.8 (1)	-	91 (1)	-
Apr.	1790 (4)	975	28 (4)	13				
May	1220 (4)	1090	22 (4)	12				
Jun.	63 (4)	30	7 (4)	1	6.7 (1)	-	64 (1)	-
Jul.	69 (4)	12	16 (4)	2.2				
Aug.	53 (4)	30	10 (4)	2.1				
Sept.	36 (4)	5.7	6 (4)	0.5	6.4 (1)	-	-	-
Average	320 (48)	670	10 (48)	9.0	6.6 (4)	0.18	70 (3)	19

Si		Fe		Mn		Ca		Mg	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
6.0 (1)	-	100 (1)	-	40 (1)	-	5.0 (1)	-	1.0 (1)	-
6.5 (1)	-	150 (1)	-	130 (1)	-	6.0 (1)	-	1.1 (1)	-
4.3 (1)	-	340 (1)	-	80 (1)	-	6.1 (1)	-	0.9 (1)	-
4.1 (1)	-	280 (1)	-	90 (1)	-	8.0 (1)	-	1.4 (1)	-
5.2 (4)	1.2	218 (4)	111	85 (4)	37	6.3 (4)	1.3	1.1 (4)	0.22

Na		K		N Ammonia		NO_3		NO_2	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
8.9 (1)	-	0.9 (1)	-	-	-	0.4 (1)	-	0.14 (1)	-
14.0 (1)	-	1.1 (1)	-	0.77 (1)	-	0.3 (1)	-	0.021 (1)	-
10.0 (1)	-	0.9 (1)	-	0.06 (1)	-	1.1 (1)	-	0.010 (1)	-
16.0 (1)	-	2.0 (1)	-	1.3 (1)	-	2.2 (1)	-	-	-
12.2 (4)	3.34	1.2 (4)	0.53	0.71 (3)	0.62	1.0 (4)	0.88	0.06 (3)	0.07

HCO_3		Hardness		Hardness Non Carb		SO_4		Cl	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
10 (1)	-	16 (1)	-	8 (1)	-	10 (1)	-	11 (1)	-
10 (1)	-	20 (1)	-	12 (1)	-	12 (1)	-	23 (1)	-
10 (1)	-	19 (1)	-	11 (1)	-	11 (1)	-	15 (1)	-
25 (1)	-	26 (1)	-	5 (1)	-	15 (1)	-	17 (1)	-
14 (4)	7.5	20 (4)	4.2	9 (4)	3	12 (4)	2.2	17 (4)	5.0

F		P		Specific Conduct.		As		Mg	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
						0 (1)	-	4.7 (1)	-
0.0 (1)	-	-	-	93 (1)	-				
0.1 (1)	-	0.20 (1)	-	131 (1)	-				
0.0 (1)	-	-	-	103 (1)	-				
0.0 (1)	-	0.29 (1)	-	148 (1)	-				
0.0 (4)	0.1	0.25 (2)	-	119 (4)	25.3				

Color	
$\bar{X}$	S
10 (1)	-
16 (1)	-
12 (1)	-
-	-
13 (3)	3.1

1972 Reach #2 Station 3	Sediment Discharge $\overline{X}$	Sediment Discharge S	Sediment Concent. $\overline{X}$	Sediment Concent. S	pH $\overline{X}$	pH S	Temp. $\overline{X}$	Temp. S
Oct.	33 (4)	17	8 (4)	4				
Nov.	37 (4)	9.0	7 (4)	1				
Dec.	44 (4)	16	5 (4)	2	6.7 (1)	-	1.0 (1)	-
Jan.	99 (4)	49	7 (4)	4				
Feb.	135 (4)	21.8	8 (4)	2				
Mar.	1880 (4)	1950	33 (4)	25	6.6 (1)	-	-	-
Apr.	3870 (4)	4430	47 (4)	47				
May	1760 (4)	1620	28 (4)	20				
Jun.	396 (4)	284	13 (4)	5.3	6.7 (1)	-	17.5 (1)	-
Jul.	127 (4)	43.4	7 (4)	2				
Aug.	74 (4)	31	8 (4)	0.5				
Sept.	44 (4)	14	7 (4)	2	7.7 (1)	-	20.0 (1)	-
Average	710 (48)	1700	15 (48)	20	6.9 (4)	0.52	12.8 (3)	10.3

Dissolved Oxygen		Dissolved Solids		Si		Fe		Mn	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
-	-	72 (1)	-	6 (1)	-	280 (1)	-	50 (1)	-
-	-	68 (1)	-	6.5 (1)	-	280 (1)	-	80 (1)	-
8.5 (1)	-	61 (1)	-	4.8 (1)	-	-	-	-	-
6.3 (1)	-	86 (1)	-	4.9 (1)	-	320 (1)	-	60 (1)	-
7.4 (2)	-	72 (4)	11	5.6 (4)	0.83	293 (3)	23.1	63 (3)	15

Ca		Mg		Na		K		N Ammonia	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
6.5 (1)	-	1.2 (1)	-	14 (1)	-	1.6 (1)	-	-	-
5.0 (1)	-	1.0 (1)	-	13 (1)	-	1.3 (1)	-	0.48 (1)	-
6.0 (1)	-	1.7 (1)	-	10 (1)	-	0.9 (1)	-	0.60 (1)	-
7.0 (1)	-	1.1 (1)	-	12 (1)	-	1.5 (1)	-	2.0 (1)	-
6.1 (4)	0.85	1.3 (4)	0.31	12 (4)	1.7	1.3 (4)	0.31	1.0 (3)	0.85

N Organic $\overline{X}$	N Organic S	N Total $\overline{X}$	N Total S	NO_3 $\overline{X}$	NO_3 S	NO_2 $\overline{X}$	NO_2 S	HCO_3 $\overline{X}$	HCO_3 S
-	-	-	-	0.30 (1)	-	-	-	18 (1)	-
0.76 (1)	-	1.5 (1)	-	0.30 (1)	-	0.007 (1)	-	10 (1)	-
1.2 (1)	-	2.5 (1)	-	0.68 (1)	-	0.006 (1)	-	13 (1)	-
1.3 (1)	-	5.6 (1)	-	1.3 (1)	-	0.960 (1)	-	24 (1)	-
1.1 (3)	0.29	3.2 (3)	2.1	0.65 (4)	0.47	0.324 (3)	0.550	16 (4)	6.1

CO_3		Hardness		Hardness Non Carb		Alkalinity		Acidity	
$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
0 (1)	-	21 (1)	-	6 (1)	-	15 (1)	-	-	-
0 (1)	-	17 (1)	-	8 (1)	-	8 (1)	-	-	-
0 (1)	-	22 (1)	-	11 (1)	-	11 (1)	-	-	-
0 (1)	-	22 (1)	-	2 (1)	-	20 (1)	-	0 (1)	-
0 (4)	0	21 (4)	2.4	7 (4)	4	14 (4)	5.2		

SO_4		Cl		F		P		Specific Conduct.	
$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
12 (1)	-	20 (1)	-	0.1 (1)	-	0.13 (1)	-	128 (1)	-
11 (1)	-	22 (1)	-	0.1 (1)	-	0.14 (1)	-	120 (1)	-
10 (1)	-	16 (1)	-	0.1 (1)	-	0.10 (1)	-	91 (1)	-
12 (1)	-	22 (1)	-	0.4 (1)	-	0.20 (1)	-	131 (1)	-
11 (4)	0.96	20 (4)	2.8	0.2 (4)	0.2	0.14 (4)	0.04	118 (4)	18.3

TABLE C.4

Mean Monthly Water Quality and Standard Deviation, Station 4.
Base Data from U.S.G.S.

1969 Reach #3 Station 4	pH		Temp.		DO		Specific Conduct.	
	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
Oct.	6.6 (4)	0.10	16 (4)	2.52	2 (4)	1.16	177 (3)	8.89
Nov.	6.8 (4)	0.15	6 (4)	2.83	9 (4)	3.62	146 (4)	13.07
Dec.	6.6 (4)	0.06	1 (4)	0.50	14 (4)	0.54	105 (4)	12.69
Jan.	6.8 (4)	0.21	1 (4)	0.58	14 (4)	0.27	150 (4)	8.58
Feb.	6.8 (4)	0.13	0 (4)	0.0	14 (4)	0.26	153 (4)	7.51
Mar.	6.8 (4)	0.06	2 (4)	0.96	13 (4)	0.29	146 (4)	6.60
Apr.	6.5 (3)	0.06	6 (3)	2.00	14 (3)	0.62	70 (4)	15.46
May	6.7 (4)	0.10	14	2.38	10 (4)	1.17	82 (4)	10.01
Jun.	6.6 (4)	0.10	22 (4)	1.26	6 (4)	0.53	112 (4)	11.53
Jul.	6.7 (4)	0.08	25 (4)	1.26	5 (4)	1.30	130 (4)	18.91
Aug.	6.6 (4)	0.08	25 (4)	0.50	6 (4)	1.06	99 (4)	19.84
Sept.	6.6 (4)	0.08	21 (4)	2.50	3 (4)	1.34	151 (4)	22.90
Average	6.7 (12)	0.11	12 (12)	9.30	9 (12)	4.63	127 (12)	32.72

TABLE C.4 (continued)

Mean Monthly Water Quality and Standard Deviation, Station 4. Base Data from U.S.G.S.

1970 Reach #3 Station 4	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	DO $\bar{X}$	DO S	Specific Conduct. $\bar{X}$	Specific Conduct. S
Oct.	6.7 (4)	0.06	14 (4)	3.16	2.7 (4)	1.08	182 (4)	6.60
Nov.	6.6 (3)	0.10	8 (3)	2.08	9.7 (3)	3.08	109 (3)	32.62
Dec.	-	-	-	-	-	-	-	-
Jan.	6.9 (2)	0.07	0 (4)	0.0	13.7 (3)	0.55	119 (3)	18.72
Feb.	6.4 (4)	0.33	1 (4)	0.50	15.0 (4)	0.21	107 (4)	15.30
Mar.	6.4 (4)	0.17	2 (2)	0.71	13.4 (4)	0.64	126 (4)	18.87
Apr.	6.1 (4)	0.06	8 (2)	1.41	13.2 (4)	1.02	73 (4)	11.17
May	6.1 (4)	0.15	16 (4)	2.06	9.5 (4)	0.76	83 (4)	10.40
Jun.	6.6 (4)	0.19	22 (4)	0.96	5.1 (4)	2.11	133 (4)	19.98
Jul.	7.0 (4)	0.35	26 (4)	2.22	6.6 (3)	0.49	152 (4)	23.43
Aug.	7.0 (4)	0.17	26 (4)	1.26	5.0 (4)	1.61	217 (4)	76.84
Sept.	6.6 (4)	0.34	20 (4)	0.96	3.0 (4)	1.15	195 (4)	26.32
Average	6.6 (11)	0.32	13 (11)	9.81	8.8 (11)	4.56	136 (11)	46.00

TABLE C.4 (continued)

Mean Monthly Water Quality and Standard Deviation, Station 4.
Base Data from U.S.G.S.

1971 Reach #3 Station 4	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	DO $\bar{X}$	DO S	Specific Conduct. $\bar{X}$	Specific Conduct. S
Oct.	7.0 (4)	0.44	16 (4)	3.00	7.2 (4)	3.43	139 (4)	17.32
Nov.	6.7 (4)	0.14	8 (4)	2.16	10.9 (4)	2.74	126 (4)	16.42
Dec.	6.8 (4)	0.10	1 (4)	1.89	14.2 (1)	-	129 (4)	11.81
Jan.	6.7 (4)	0.20	0 (4)	0.50	-	-	162 (4)	18.17
Feb.	6.8 (4)	0.17	0 (4)	0.00	15.1 (3)	0.72	179 (4)	11.18
Mar.	6.7 (4)	0.10	2 (4)	0.82	-	-	150 (4)	10.05
Apr.	6.4 (3)	0.12	6 (4)	1.83	13.8 (3)	1.46	82 (4)	16.86
May	6.0 (3)	0.06	13 (4)	3.16	10.0 (3)	1.11	83 (4)	14.64
Jun.	6.2 (4)	0.05	23 (4)	3.42	5.3 (4)	2.25	137 (4)	17.61
Jul.	7.0 (3)	0.68	26 (4)	0.82	6.8 (4)	2.81	193 (2)	26.16
Aug.	6.5 (3)	0.17	26 (3)	0.0	4.8 (3)	0.68	149 (3)	9.17
Sept.	6.4 (4)	0.13	22 (4)	2.16	3.2 (3)	1.26	163 (4)	44.58
Average	6.6 (12)	0.31	12 (12)	10.41	9.1 (10)	4.28	141 (12)	33.65

TABLE C.4 (continued)

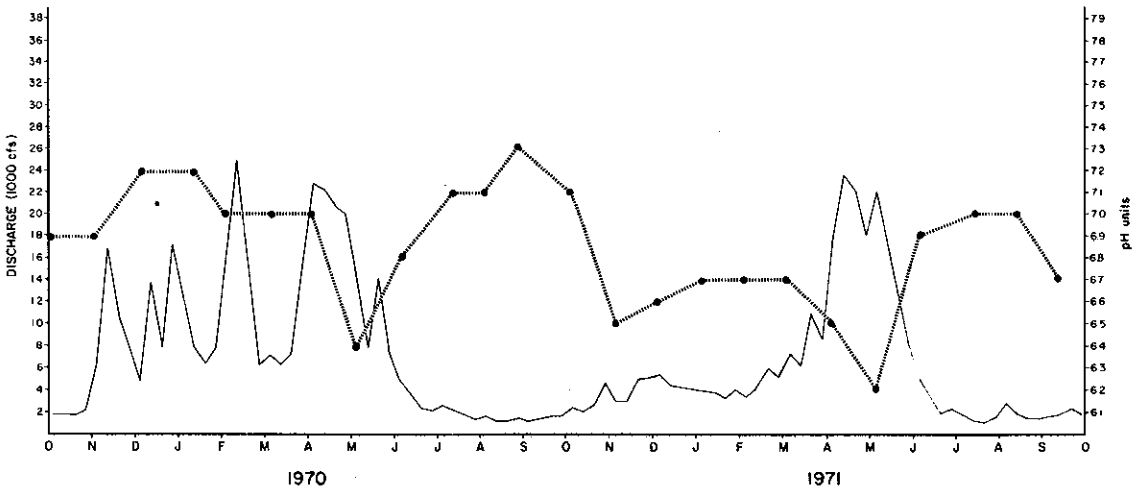
Mean Monthly Water Quality and Standard Deviation, Station 4. Base Data from U.S.G.S.

1972 Reach #3 Station 4	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	DO $\bar{X}$	DO S	Specific Conduct. $\bar{X}$	Specific Conduct. S
Oct.	6.3 (4)	0.05	16 (4)	1.41	5.6 (2)	0.49	159 (4)	21.65
Nov.	6.6 (4)	0.17	8 (4)	5.51	9.4 (2)	1.70	165 (4)	6.50
Dec.	6.7 (3)	0.06	0 (3)	0.58	6.7 (3)	0.06	186 (3)	10.21
Jan.	6.7 (4)	0.13	1 (4)	0.5	6.7 (4)	0.13	186 (4)	12.14
Feb.	6.7 (4)	0.05	0 (4)	0.5	6.7 (4)	0.05	182 (4)	33.13
Mar.	6.6 (4)	0.10	2 (4)	0.58	6.6 (4)	0.10	144 (4)	42.48
Apr.	6.5 (4)	0.08	6 (4)	1.83	6.5 (4)	0.08	91 (4)	16.58
May	6.5 (4)	0.08	14 (4)	4.11	6.5 (4)	0.08	87 (4)	14.01
Jun.	6.4 (4)	0.05	20 (4)	0.82	6.4 (4)	0.05	120 (4)	18.68
Jul.	6.4 (4)	0.10	25 (4)	2.08	6.4 (4)	0.10	122 (3)	7.00
Aug.	6.5 (4)	0.17	24 (4)	1.41	6.5 (4)	0.17	-	-
Sept.	6.3 (4)	0.0	21 (4)	1.71	6.3 (4)	0.0	181 (2)	2.83
Average	6.5 (12)	0.15	11 (12)	9.70	6.7 (12)	0.90	148 (11)	37.40

TABLE C.4 (continued)

Mean Monthly Water Quality and Standard Deviation, Station 4.
Base Data from U.S.G.S.

1973 Reach #3 Station 4	pH $\bar{X}$	pH S	Temp. $\bar{X}$	Temp. S	DO $\bar{X}$	DO S	Specific Conduct. $\bar{X}$	Specific Conduct. S
Oct.	6.3 (4)	0.12	13 (4)	3.6	6.0 (4)	1.3	143 (4)	11.2
Nov.								
Dec.								
Jan.								
Feb.								
Mar.								
Apr.								
May	6.6 (4)	0.08	15 (4)	1.4	10.3 (4)	0.26	89 (4)	4.2
Jun.	6.5 (4)	0.21	21 (4)	2.2	7.5 (4)	1.3	106 (4)	16.4
Jul.	6.4 (4)	0.10	24 (4)	1.6	8.2 (4)	1.1	108 (4)	27.8
Aug.	6.3 (4)	0.10	26 (4)	0.96	5.8 (4)	1.1	148 (4)	34.6
Sept.	6.5 (4)	0.17	22 (4)	4.0	5.2 (4)	1.5	170 (4)	6.70
Average	6.4 (4)	0.16	20 (24)	5.1	7.2 (24)	2.1	123 (24)	36.4



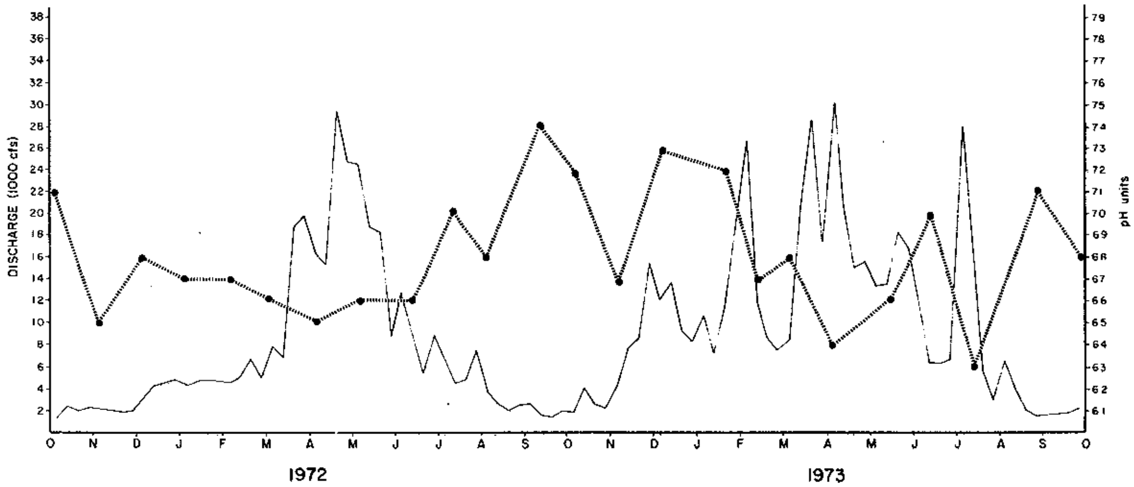


Figure C1-1
1970-1973 pH Water Quality Station 1

pH
Discharge

Merrimack River Diversion Study

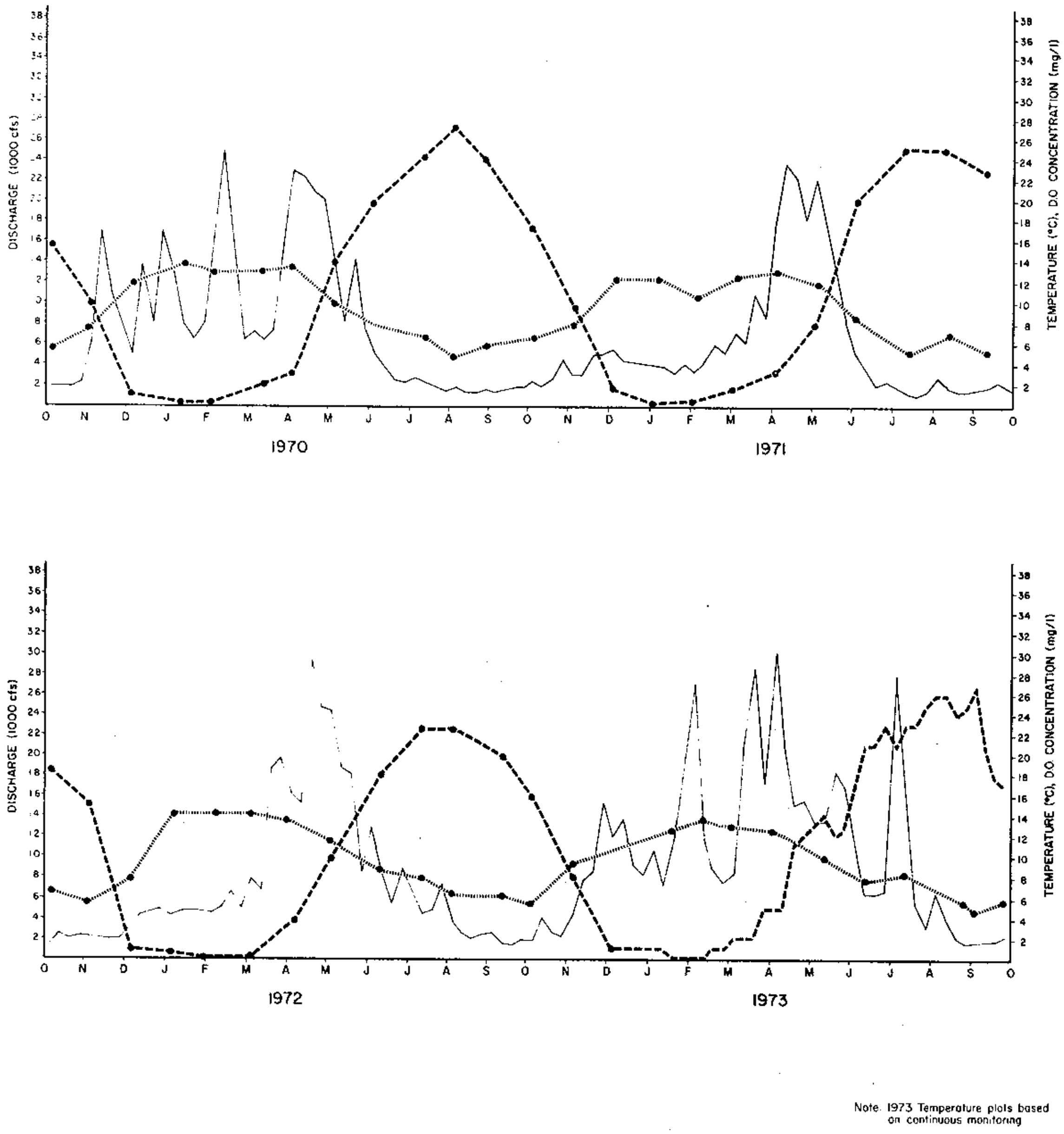


Figure C1-2
1970 -1973 Dissolved Oxygen Temperature
Water Quality Station 1

Merrimack River Diversion Study

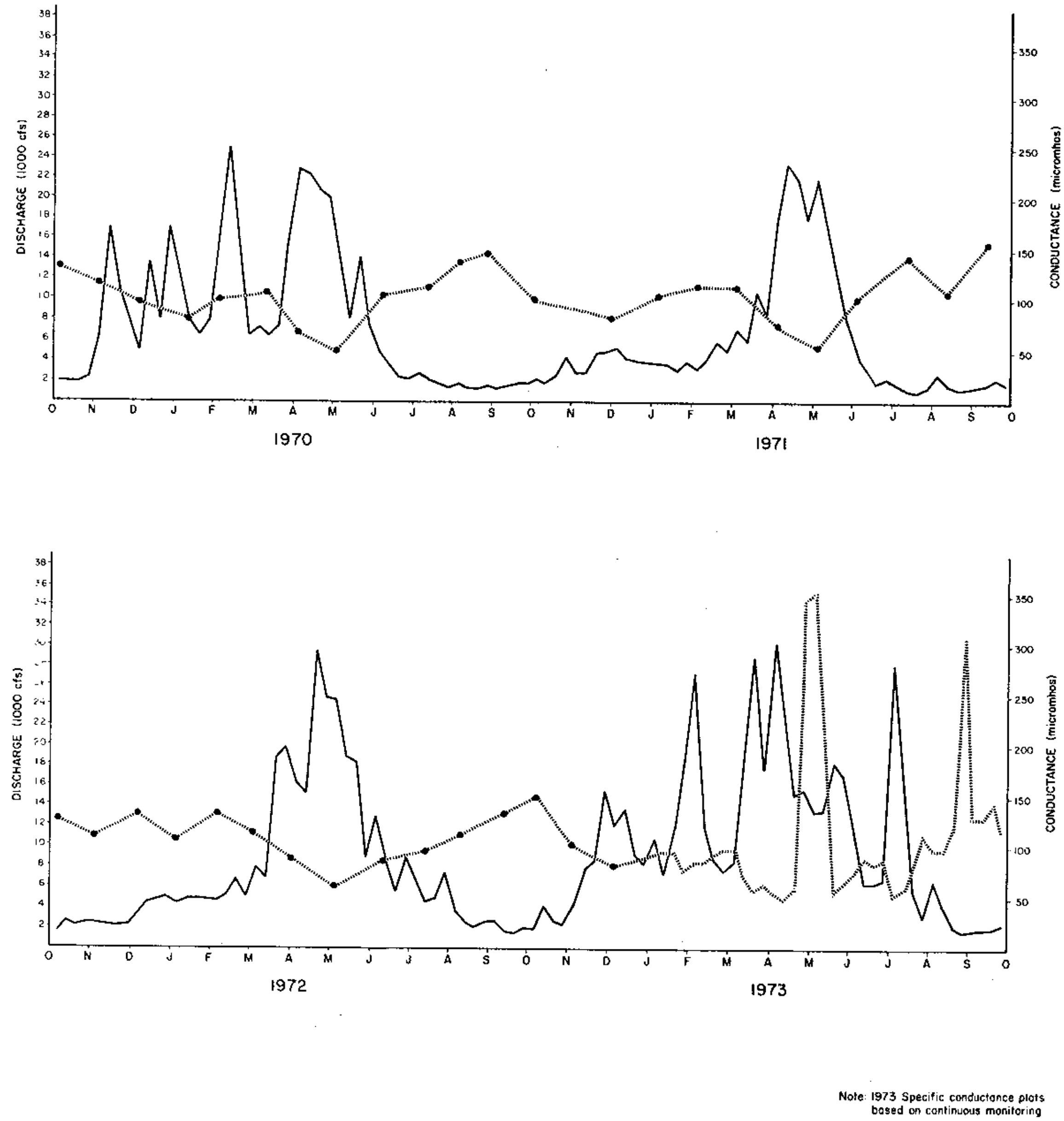


Figure C1-3
1970-1973 Specific Conductance Water Quality Station 1

Specific Conductance
Discharge

Merrimack River Diversion Study

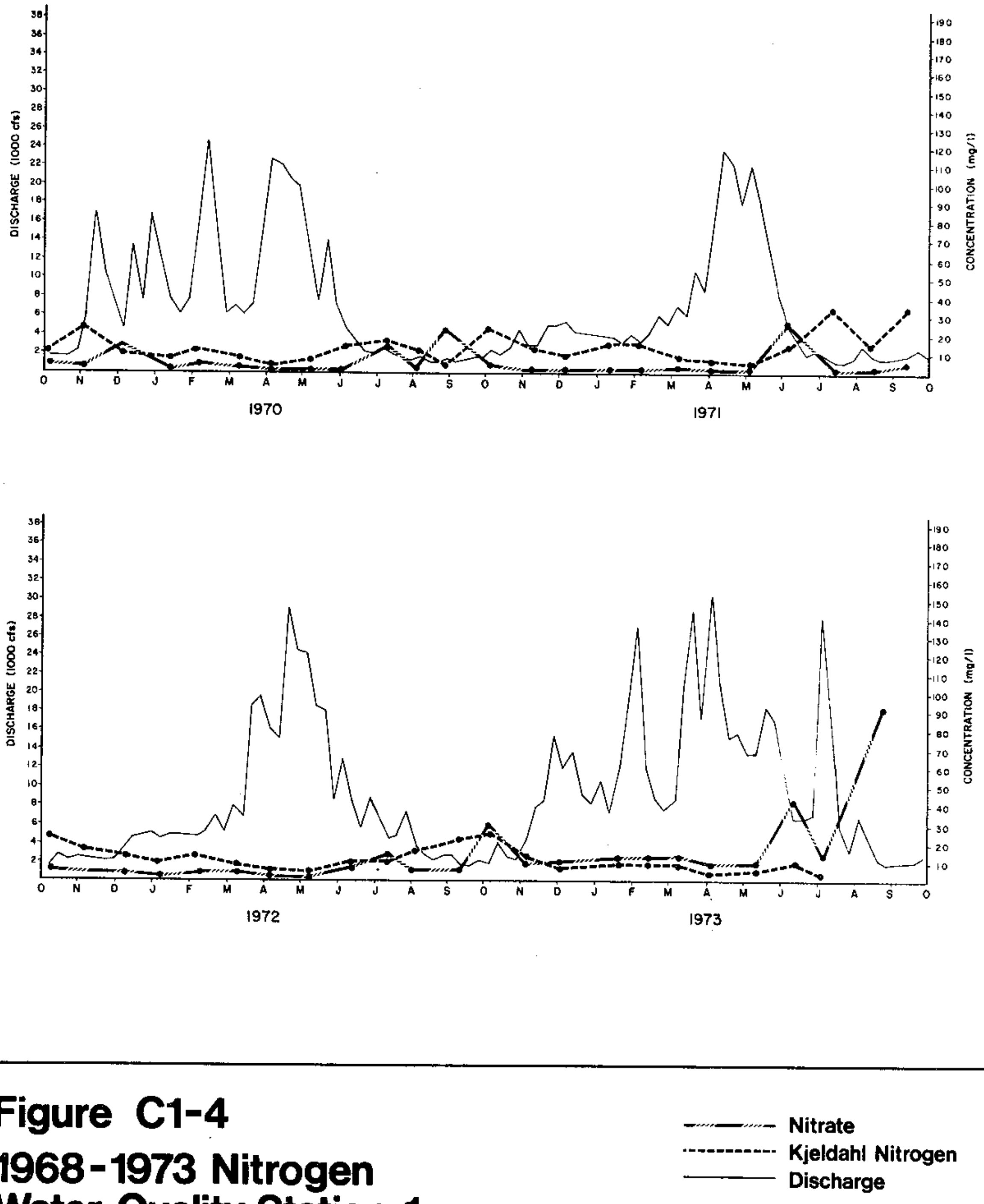


Figure C1-4

1968-1973 Nitrogen Water Quality Station 1 Merrimack River

Merrimack River Diversion Study

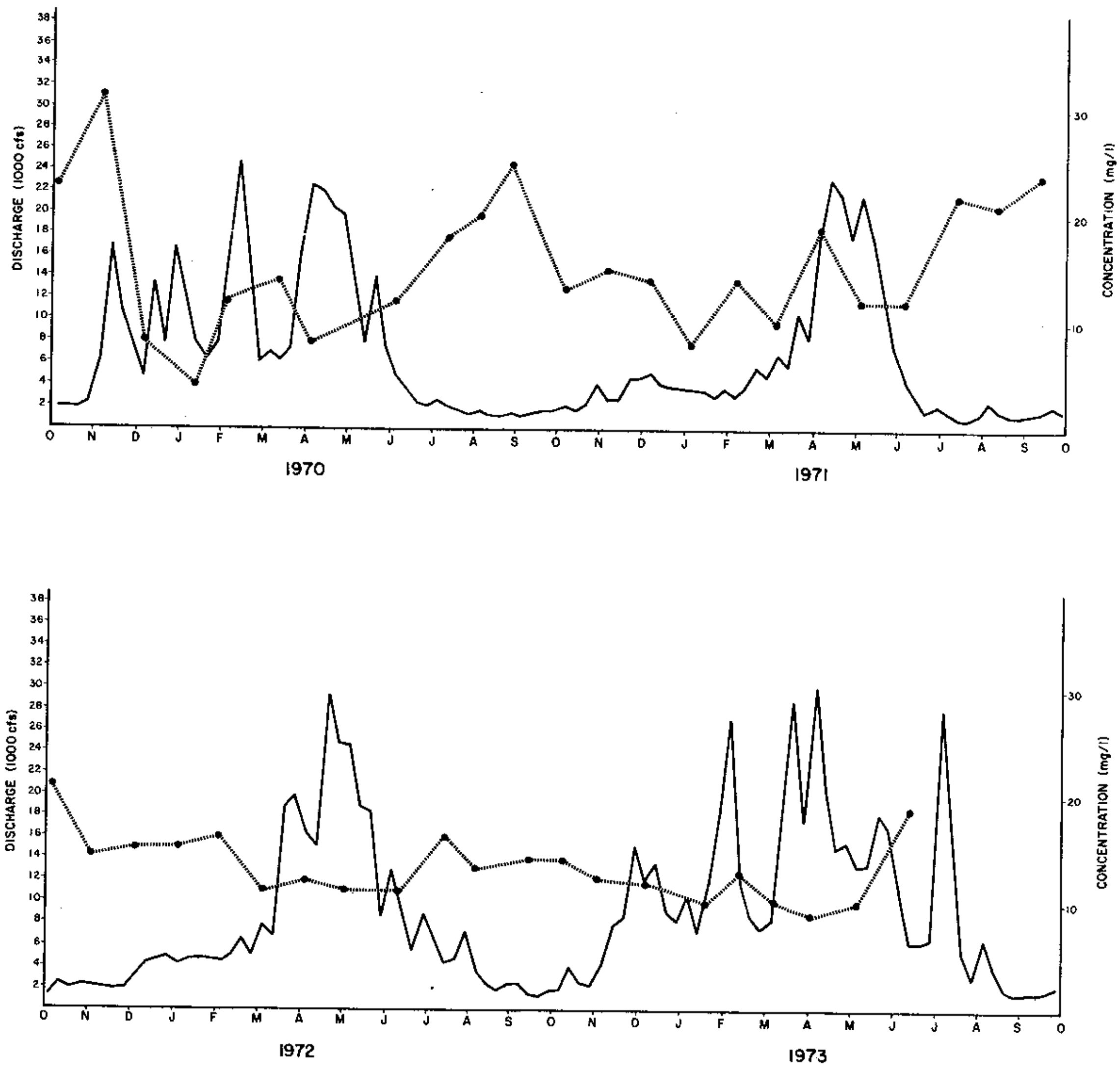


Figure C1-5
1970 - 1973 Chemical Oxygen Demand Water Quality Station 1

Chemical Oxygen Demand
Discharge

Merrimack River Diversion Study

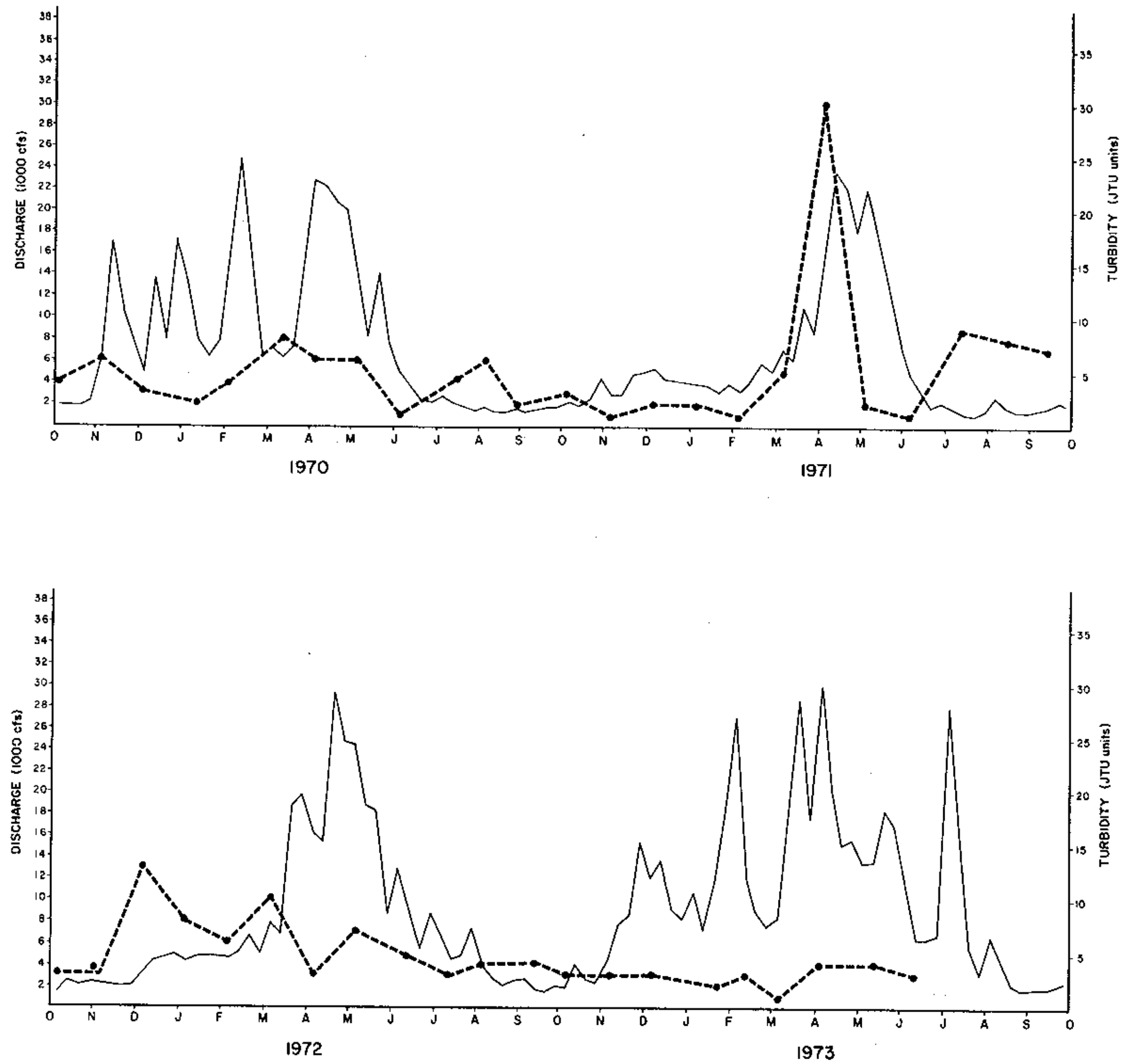
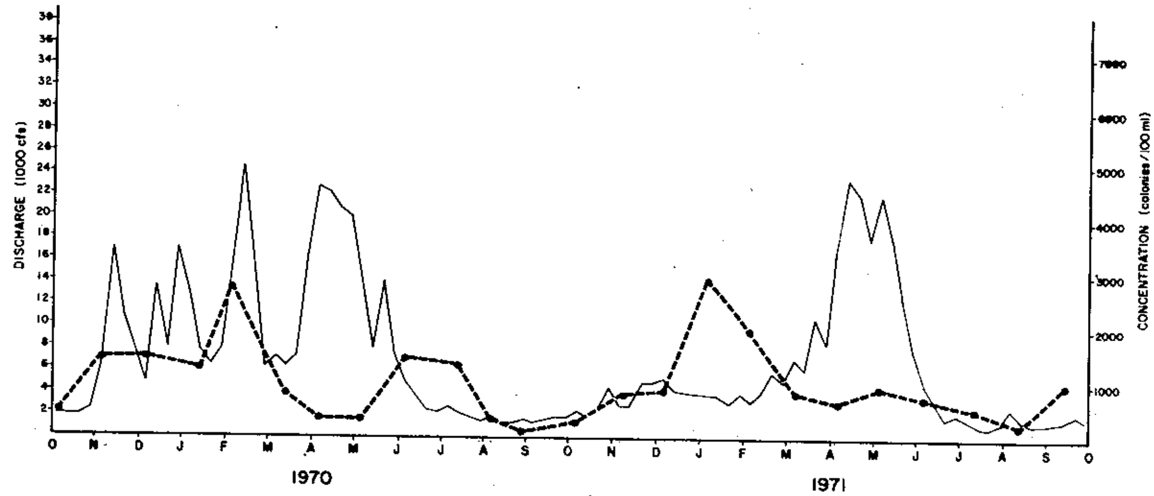


Figure C1-6
1970 - 1973 Turbidity Water Quality Station 1

Turbidity
Discharge

Merrimack River Diversion Study



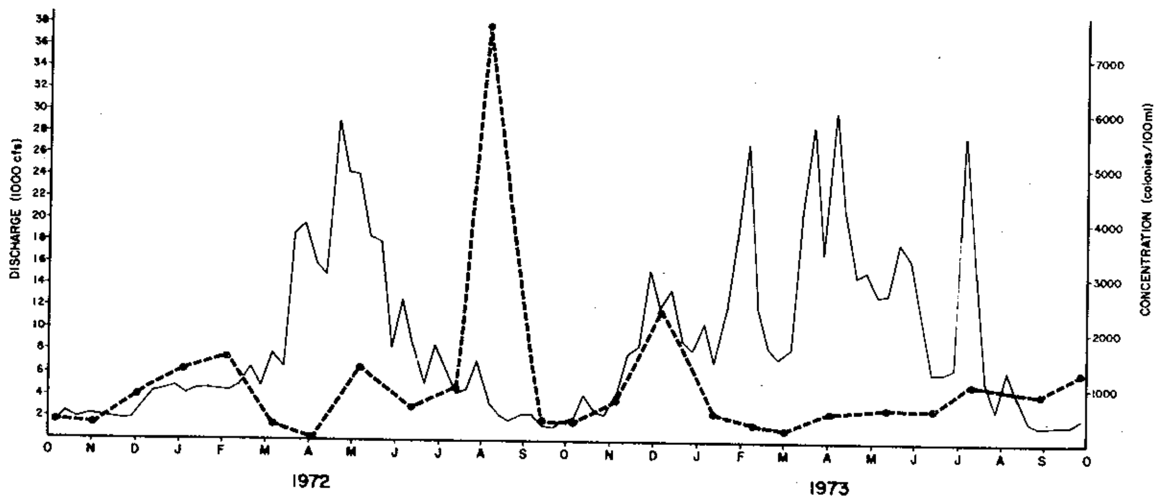


Figure C1-7

1970-1973 Fecal Coliform Bacteria Water Quality Station 1

Fecal Coliform Bacteria

Discharge

Merrimack River Diversion Study

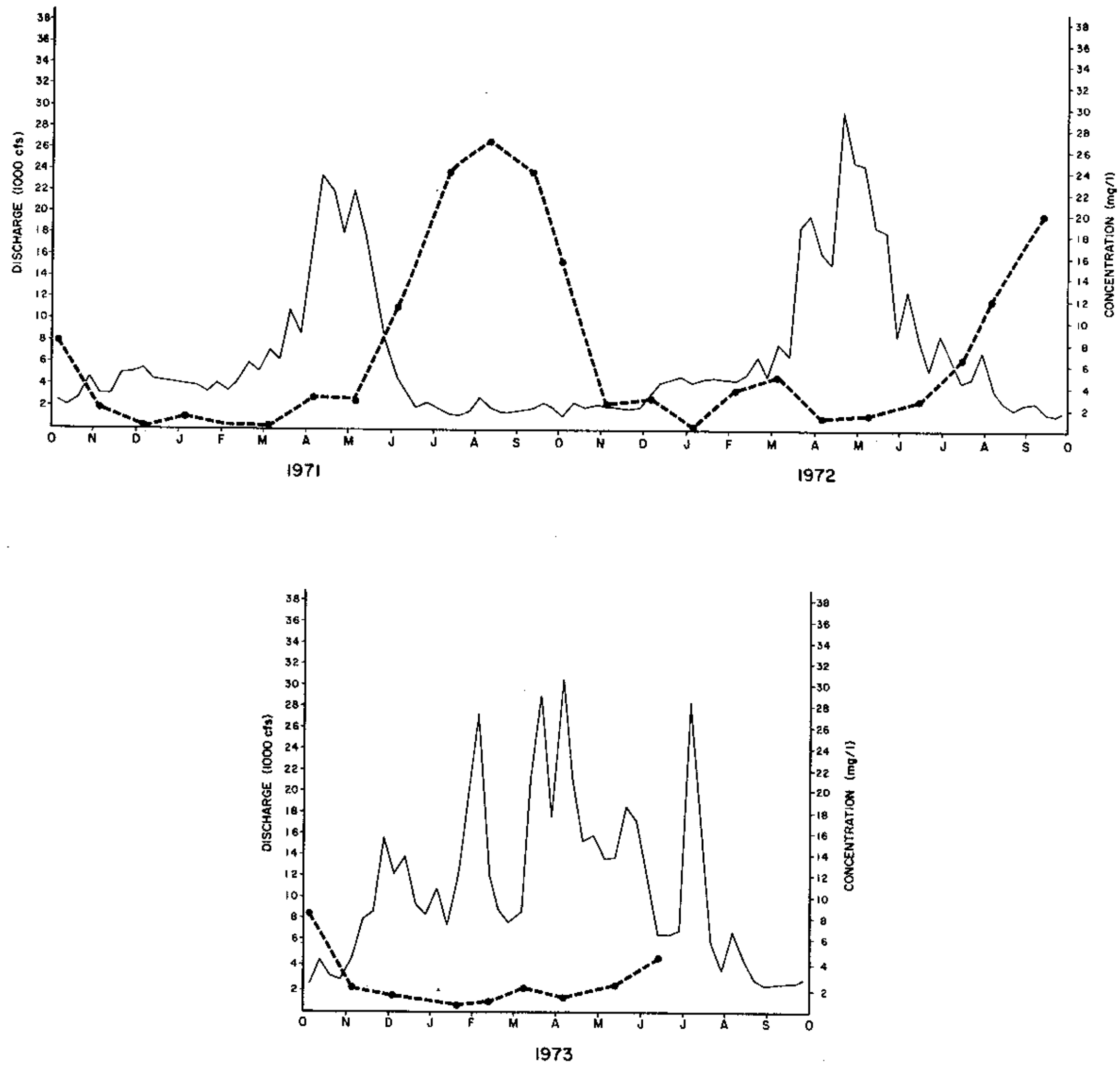
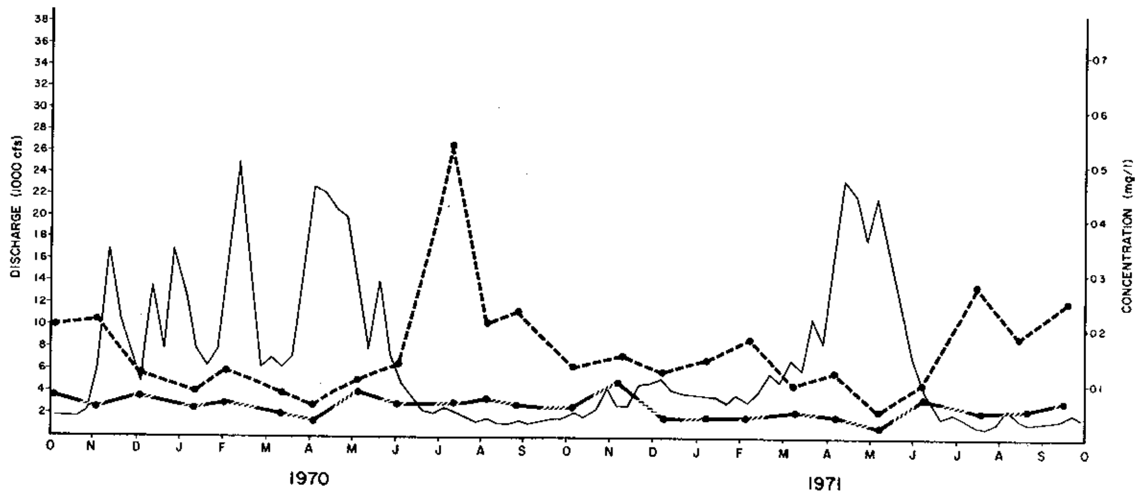


Figure C1-8
1971 - 1973 Chlorophyll A
Water Quality Station 1

-------- Chlorophyll A
——— Discharge

Merrimack River Diversion Study



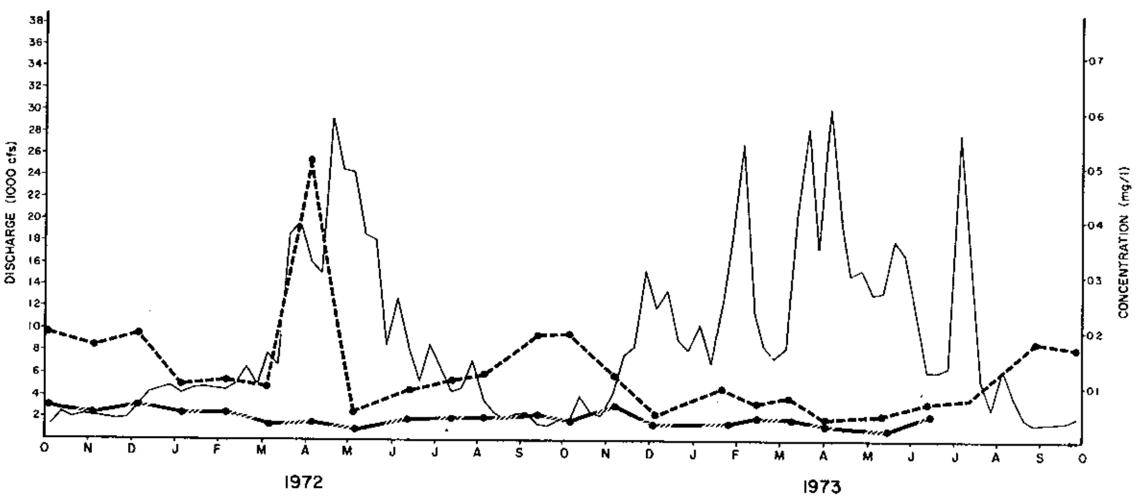
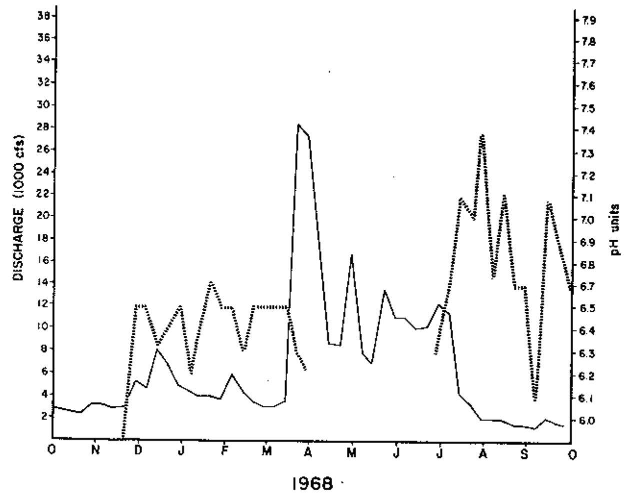
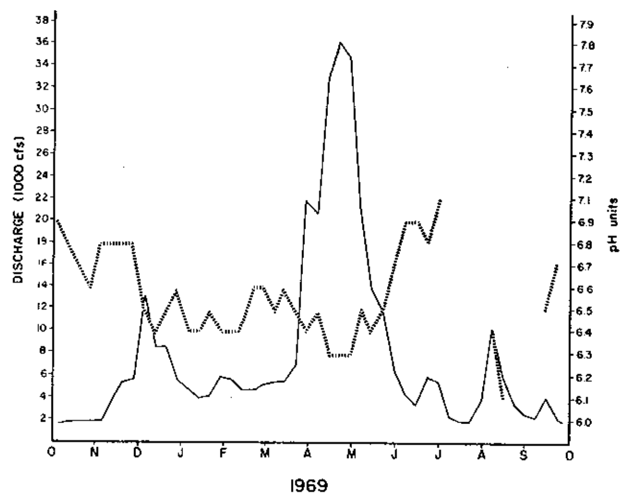


Figure C1-9
1970 - 1973 Total Phosphorus Methylene Active Substances Water Quality Station 1

Total Phosphorus
Methylene Active Substances
Discharge

Merrimack River Diversion Study



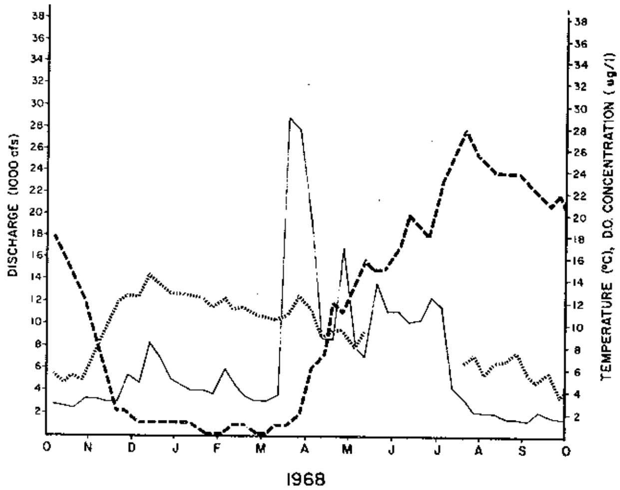


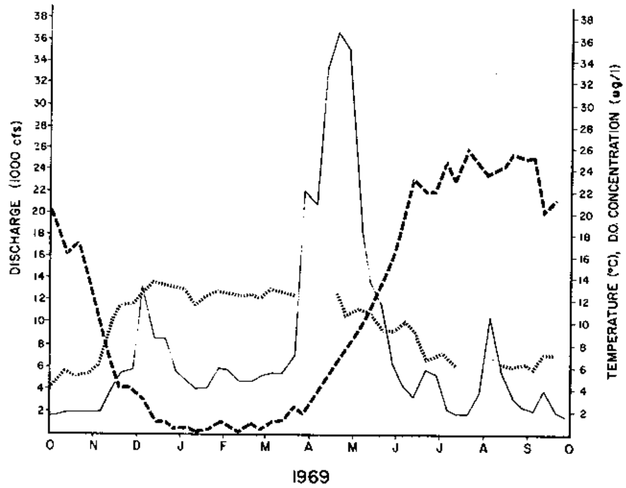
Note: Plots based on continuous monitoring

Figure C2-1
1968-1969 pH Water Quality Station 2

pH
Discharge

Merrimack River Diversion Study



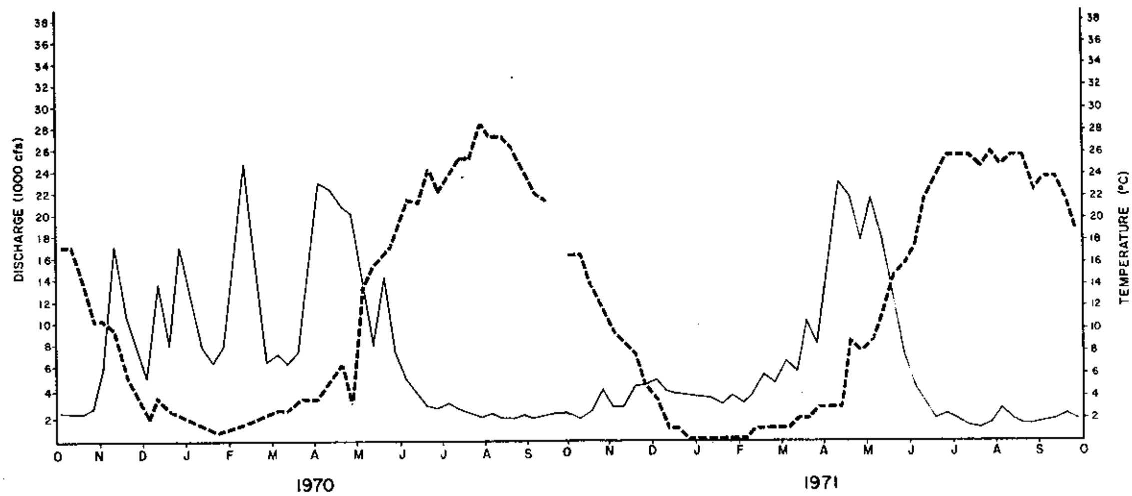


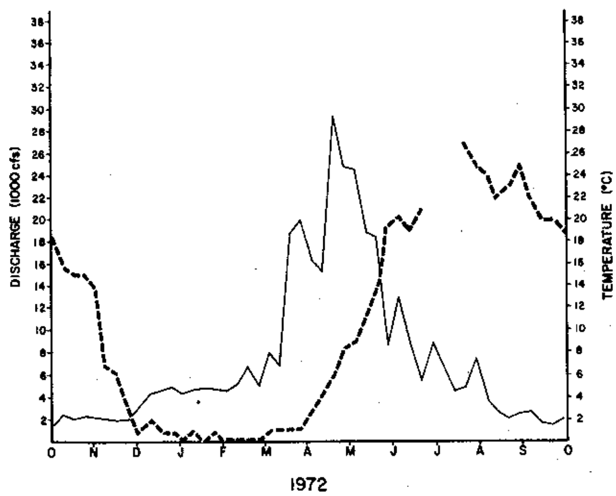
Note: Plots based on continuous monitoring

Figure C2-2a
1968-1969 Dissolved Oxygen Temperature
Water Quality Station 2

Merrimack River Diversion Study

··················	Dissolved Oxygen
----------	Temperature
————	Discharge



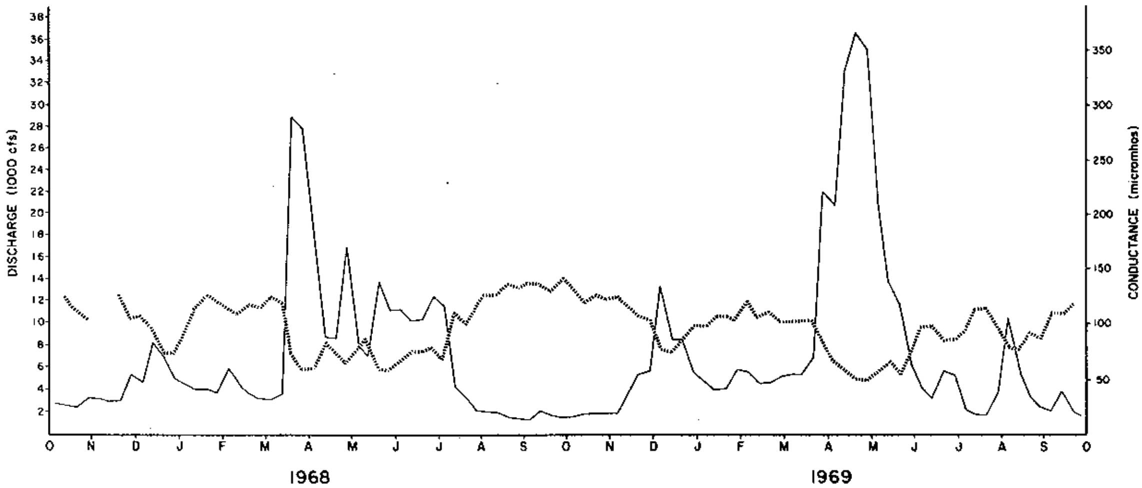


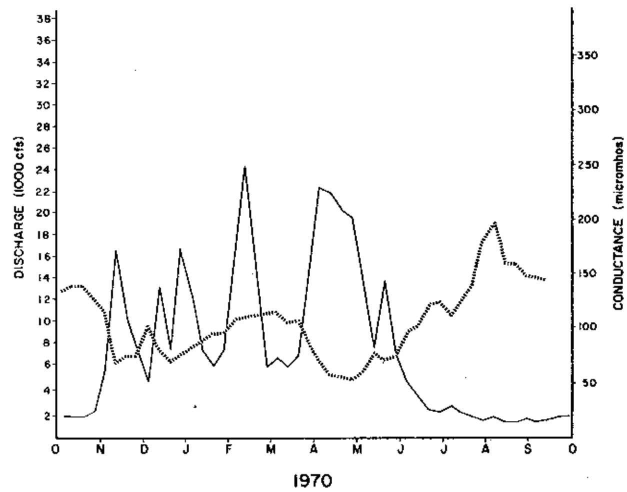
Note: Plots based on continuous monitoring

Figure C2-2b
1970-1972 Temperature Water Quality Station 2

------------ Temperature
———— Discharge

Merrimack River Diversion Study



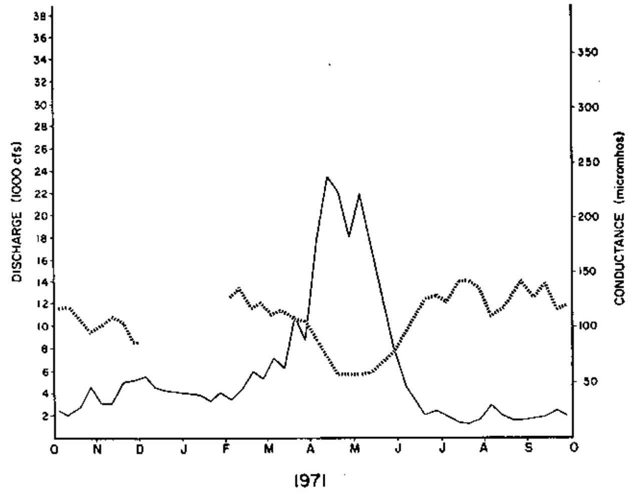


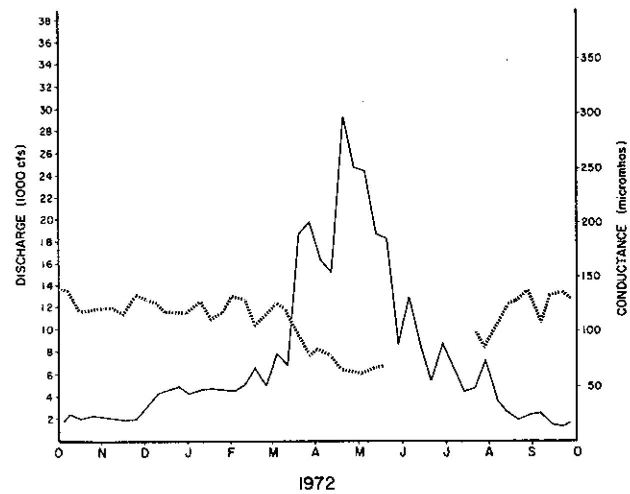
Note: Plots based on continuous monitoring

Figure C2-3a
1968-1970 Specific Conductance Water Quality Station 2

······· Specific Conductance
—— Discharge

Merrimack River Diversion Study



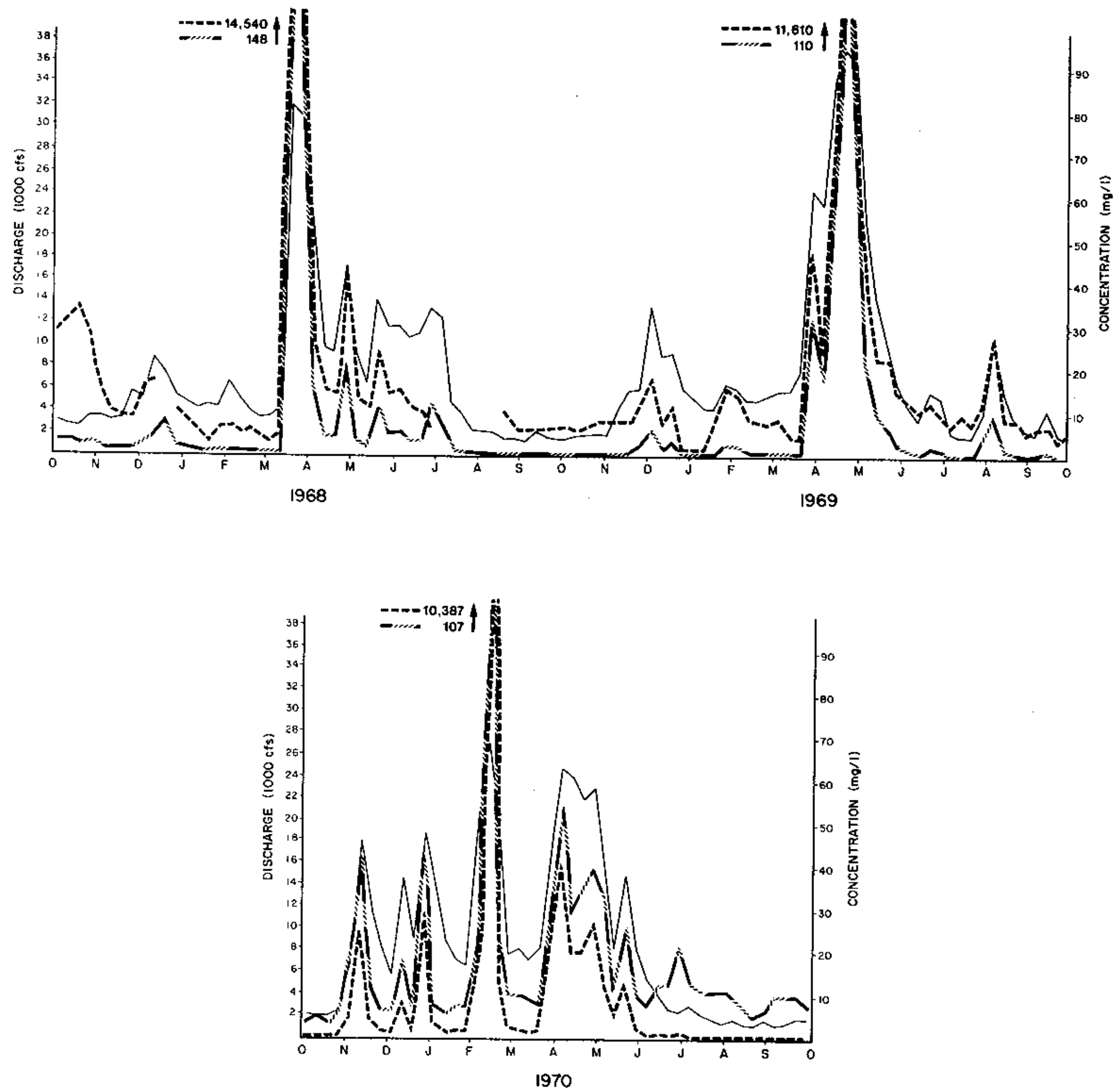


Note: Plots based on continuous monitoring

Figure C2-3b
1971 -1972 Specific Conductance Water Quality Station 2

Specific Conductance
Discharge

Merrimack River Diversion Study

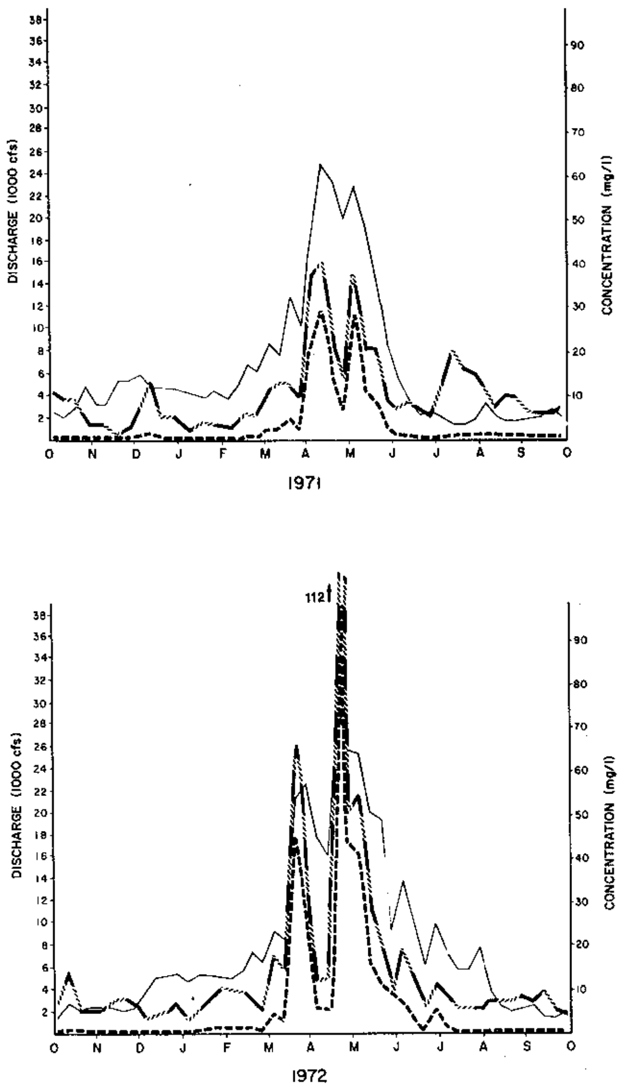


Note: Plots based on continuous monitoring

Figure C3-1a
1968-1970 Sediments Water Quality Station 3

Sediment Concentration
Sediment Discharge
Discharge

Merrimack River Diversion Study

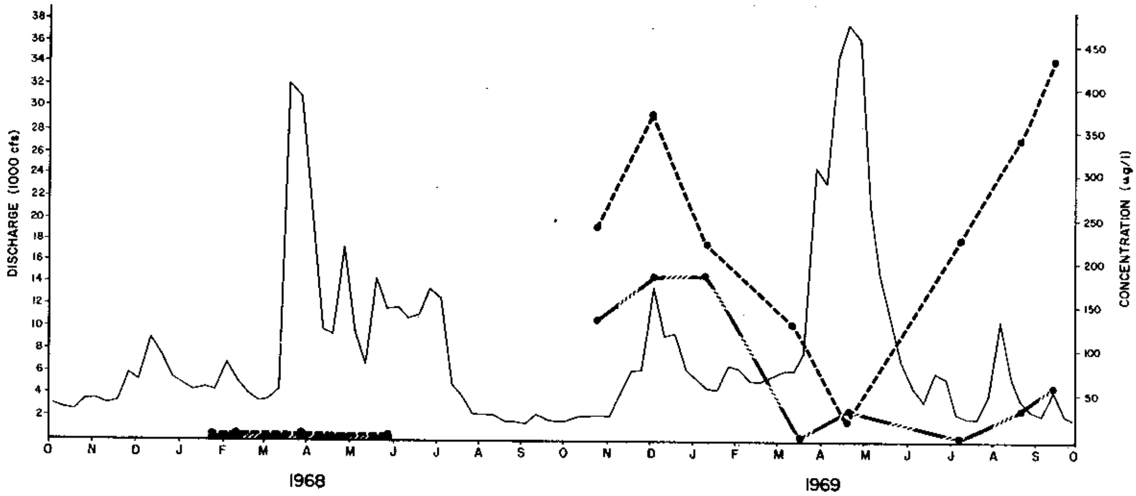


Note: Plots based on continuous monitoring

Figure C3-1b
1971 -1972 Sediments Water Quality Station 3

Sediment Concentration
Sediment Discharge
Discharge

Merrimack River Diversion Study



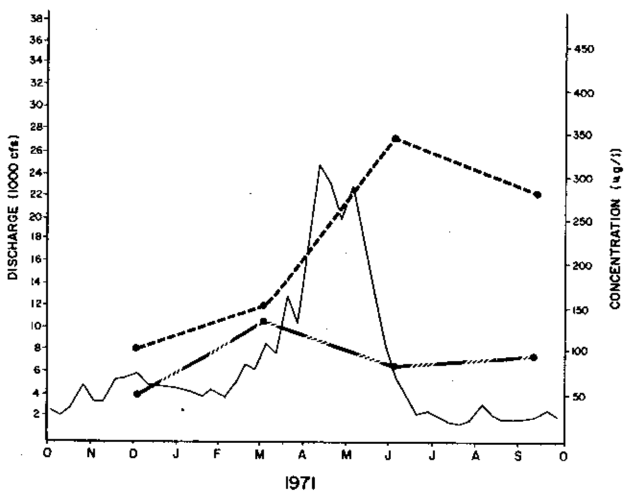


Figure C3-2
1968,1969,1971 Iron, Manganese
Water Quality Station 3

Merrimack River Diversion Study

Iron
Manganese
Discharge

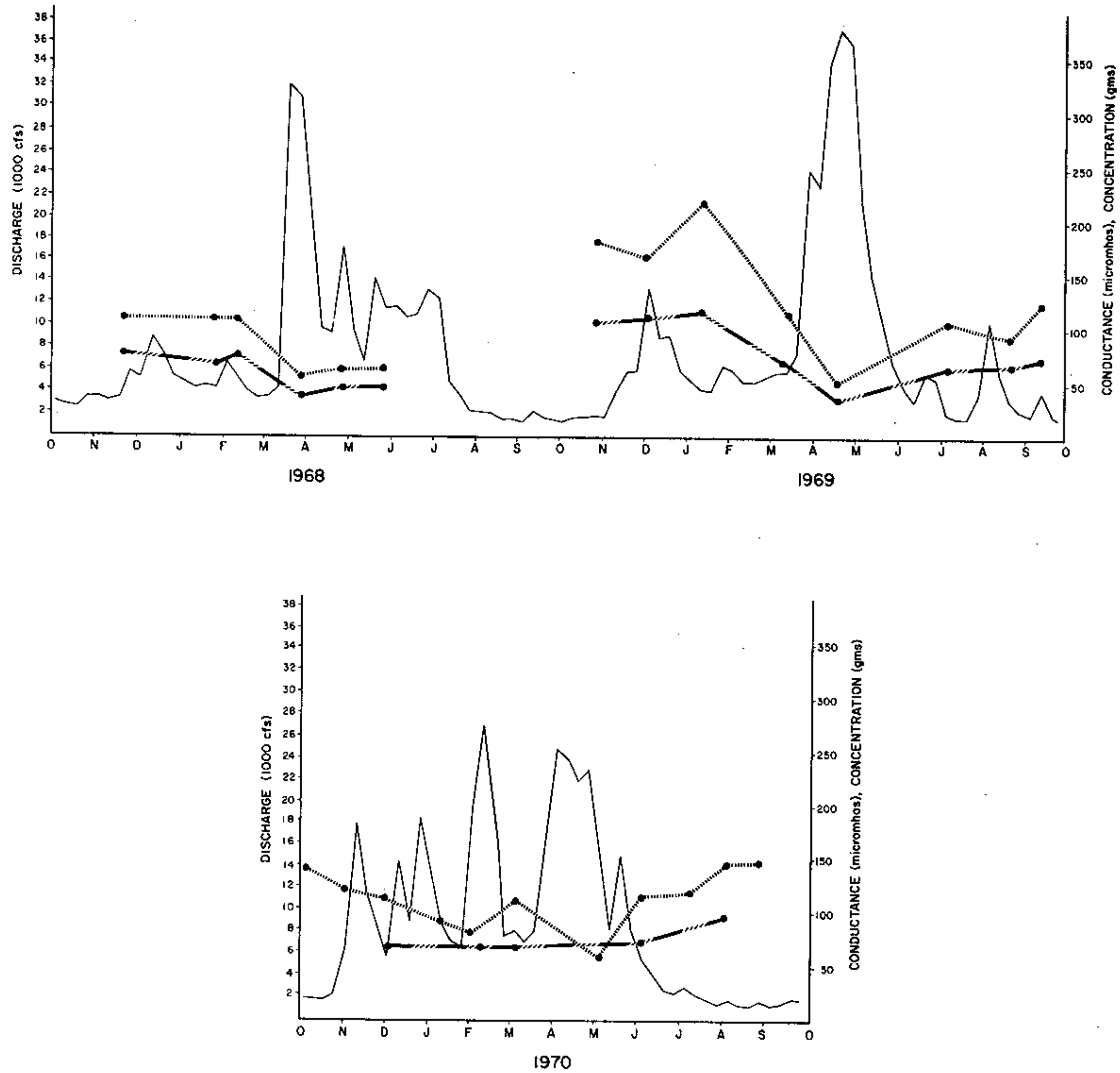


Figure C3-3a

1968-1970 Specific Conductance, Dissolved Solids
Water Quality Station 3

Merrimack River Diversion Study

Specific Conductance
Dissolved Solids
Discharge

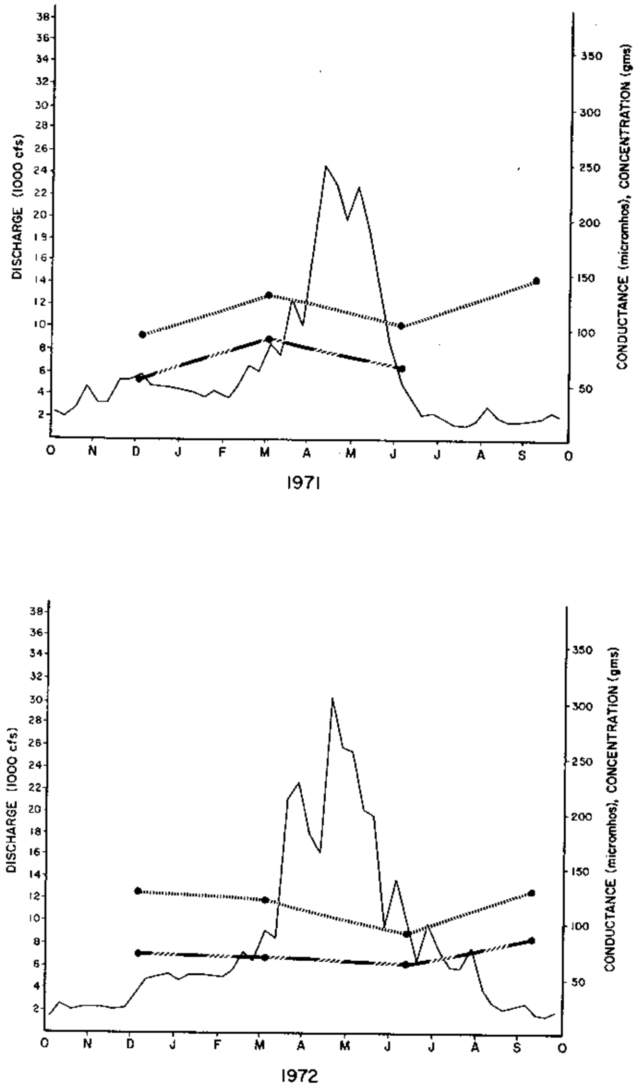


Figure C3-3b
1971 - 1972 Specific Conductance, Dissolved Solids
Water Quality Station 3

Specific Conductance
Dissolved Solids
Discharge

Merrimack River Diversion Study

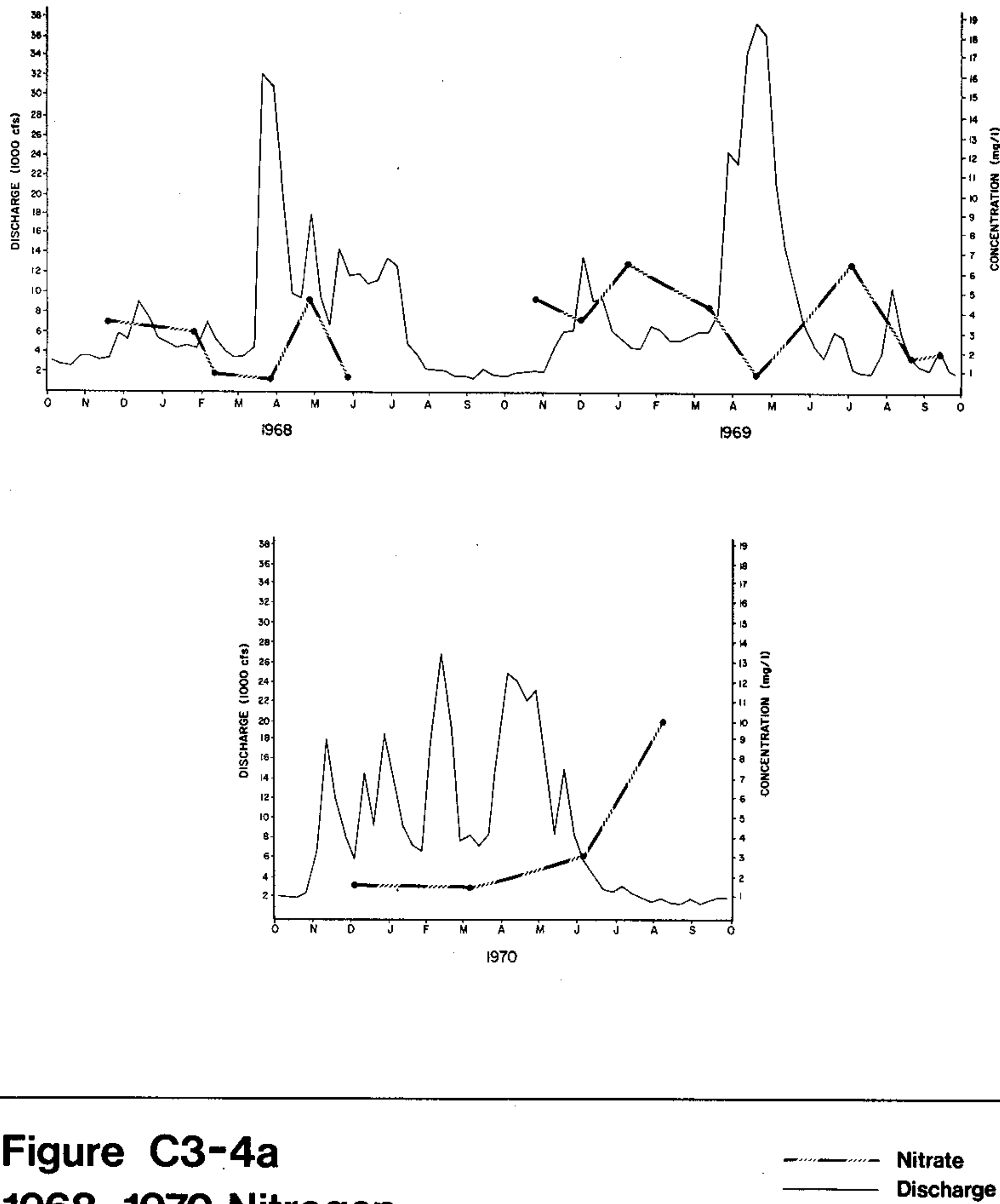
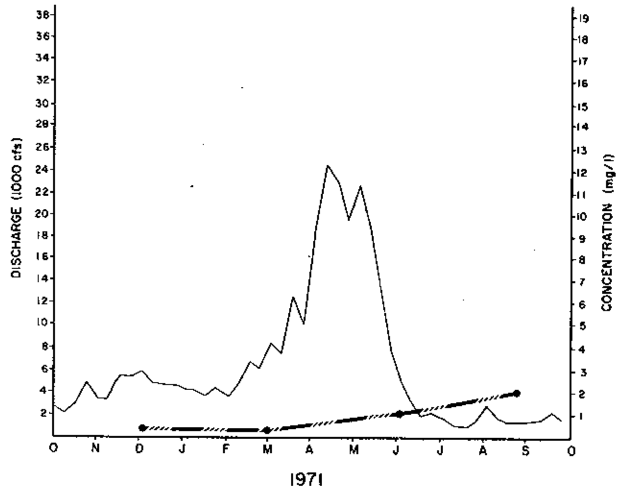


Figure C3-4a
1968-1970 Nitrogen
Water Quality Station 3
Merrimack River

Merrimack River Diversion Study



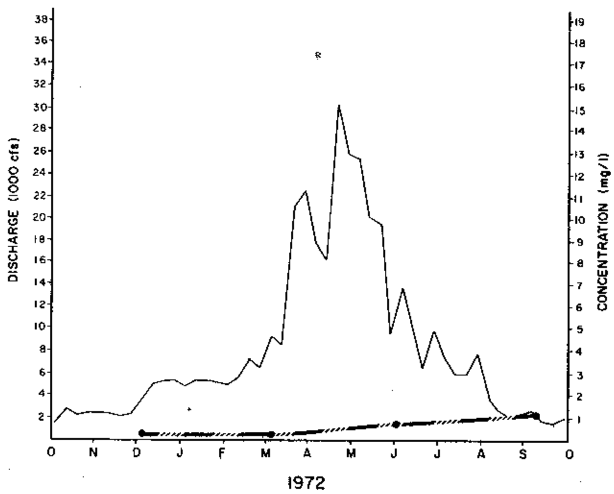


Figure C3-4b
1971 - 1973 Nitrogen Water Quality Station 3 Merrimack River

Merrimack River Diversion Study

Nitrate
Discharge

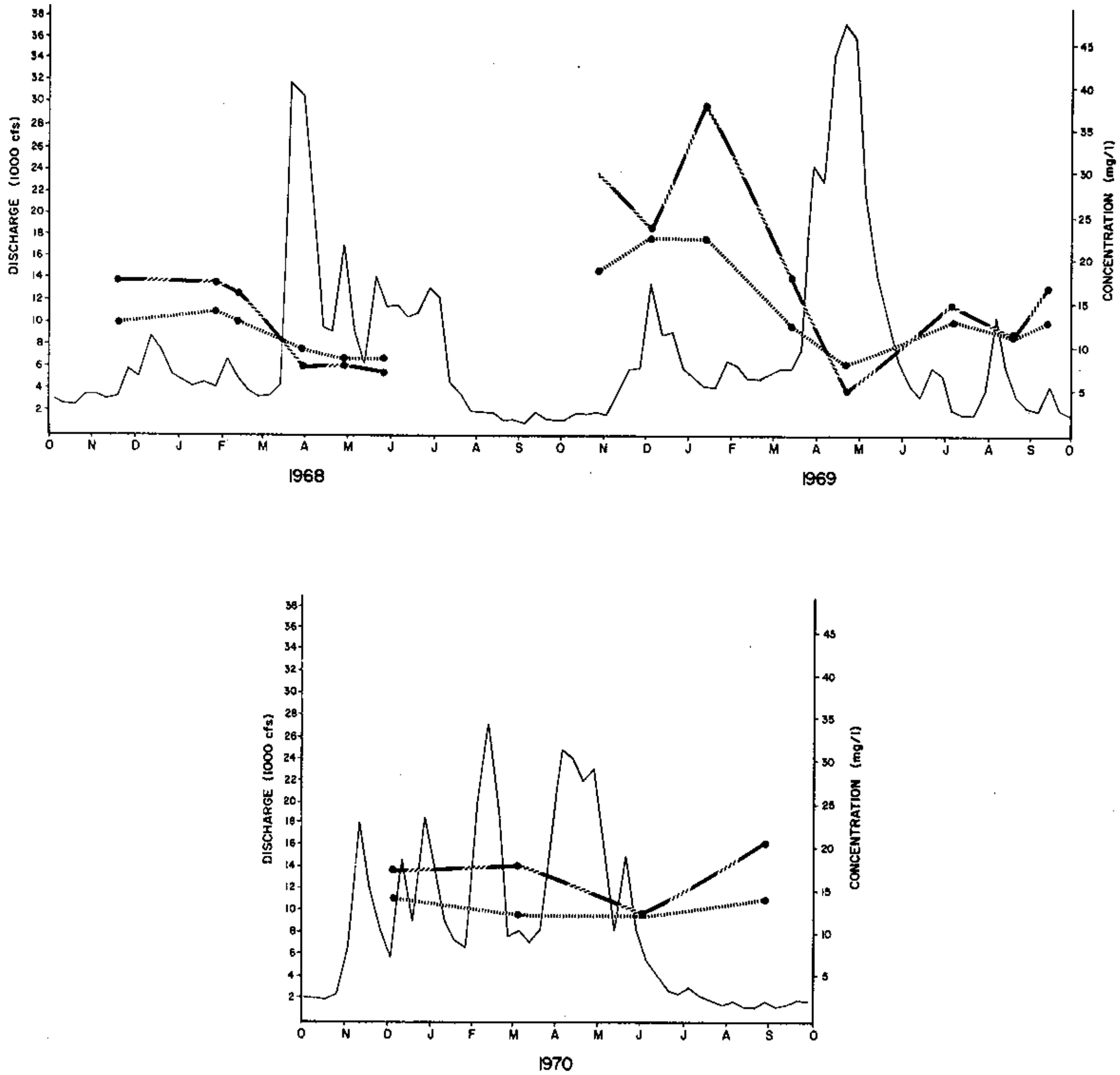


Figure C3-5a
1968-1970 Sulfate, Chloride Water Quality Station 3

Sulfate
Chloride
Discharge

Merrimack River Diversion Study

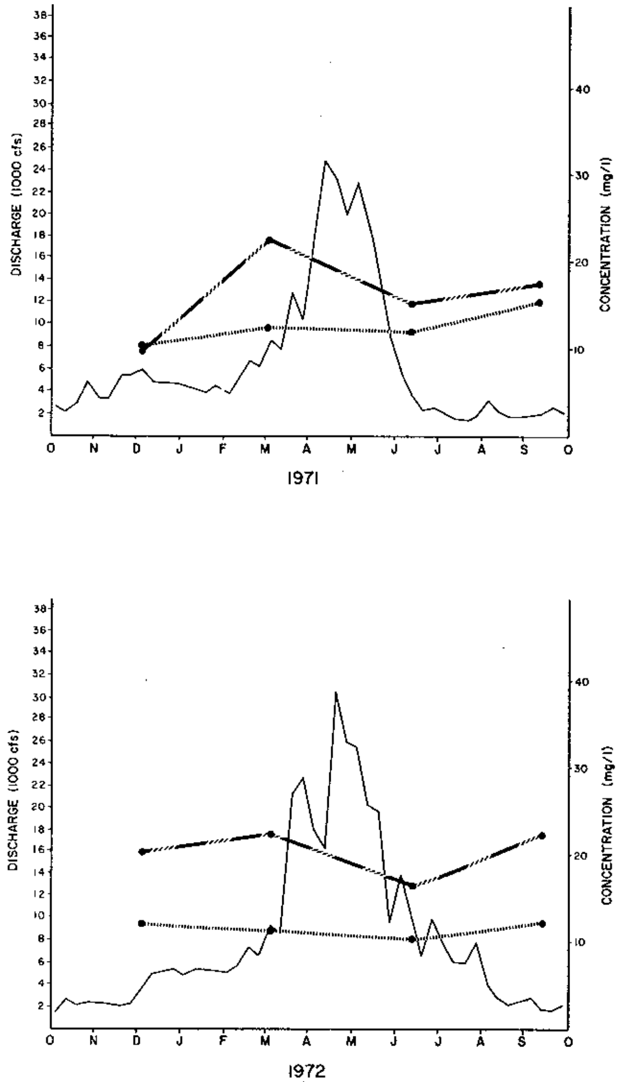


Figure C3-5b
1971 - 1972 Sulfate, Chloride Water Quality Station 3

Sulfate
Chloride
Discharge

Merrimack River Diversion Study

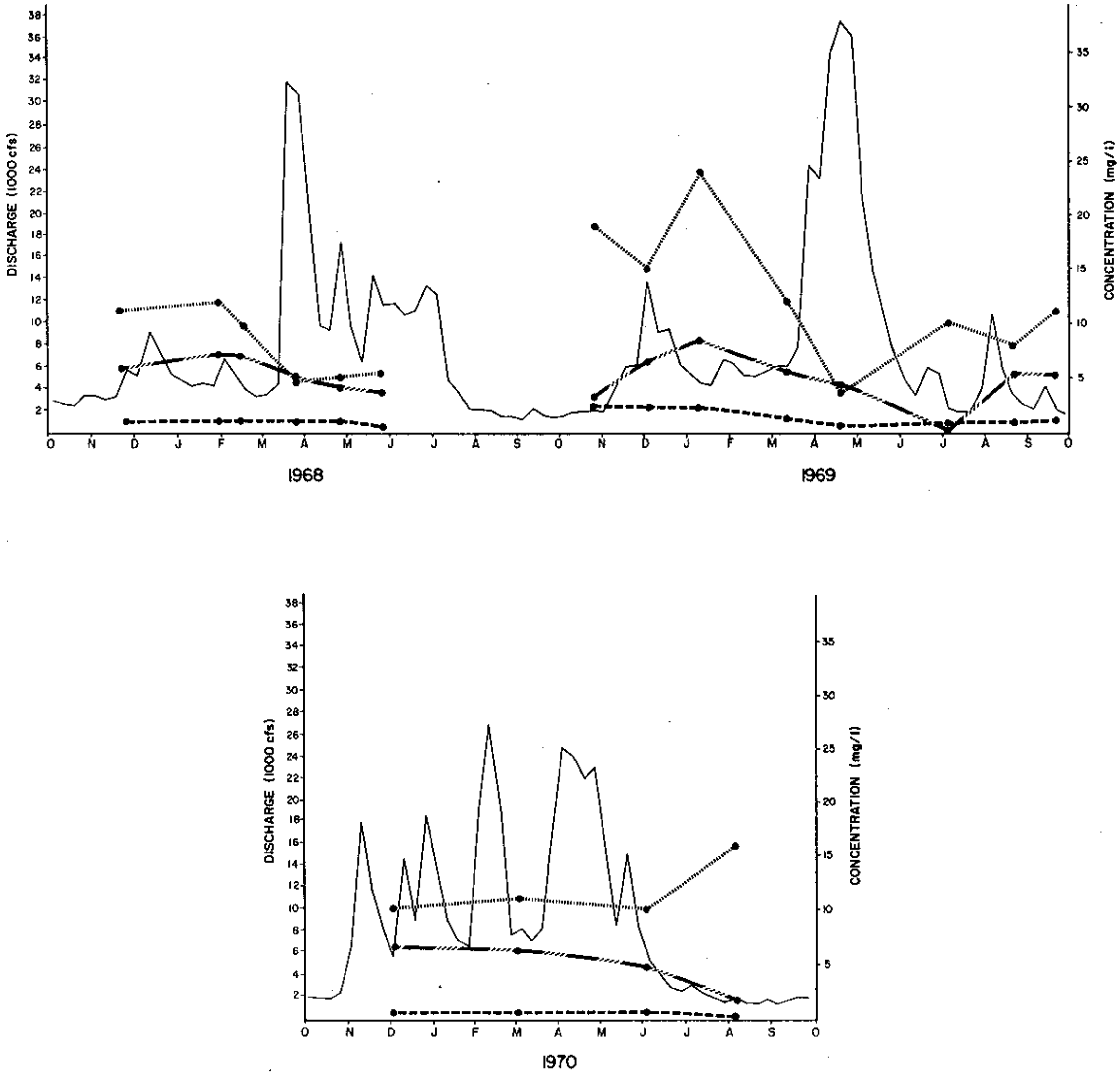


Figure C3-6a
1968-1970 Potassium, Sodium, Silica
Water Quality Station 3

Merrimack River Diversion Study

Potassium
Sodium
Silica
Discharge

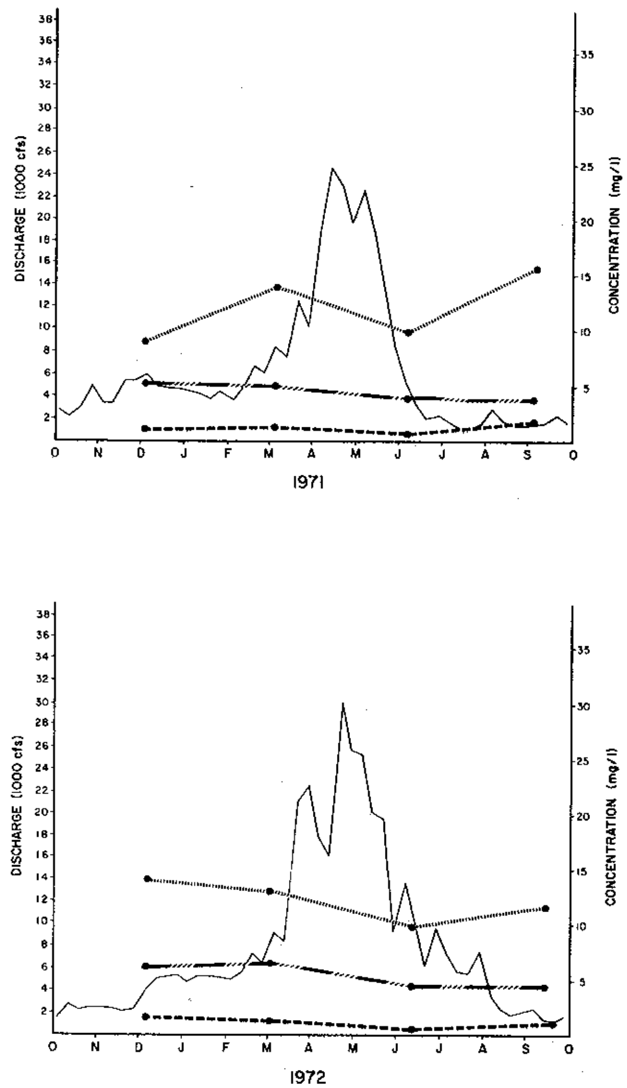
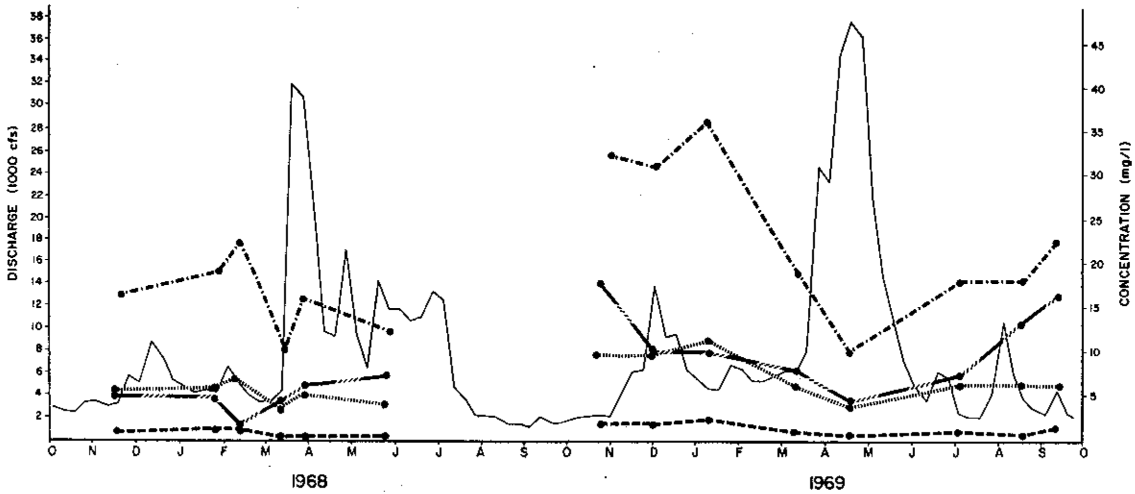


Figure C3-6b
1971 -1972 Potassium, Sodium, Silica
Water Quality Station 3

Merrimack River Diversion Study

- - - - - Potassium
········· Sodium
-·-·-·- Silica
——— Discharge



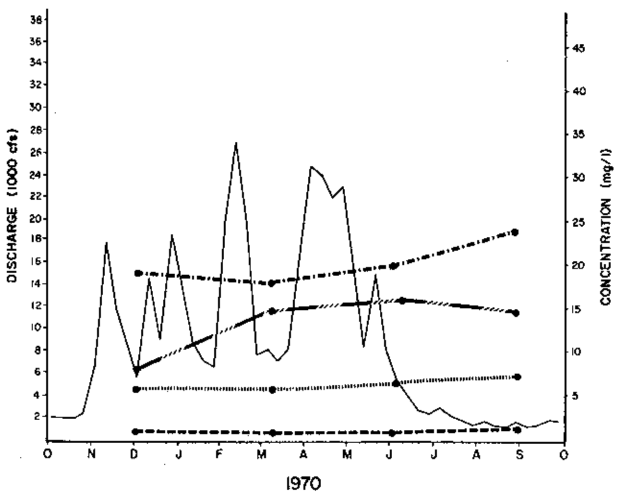
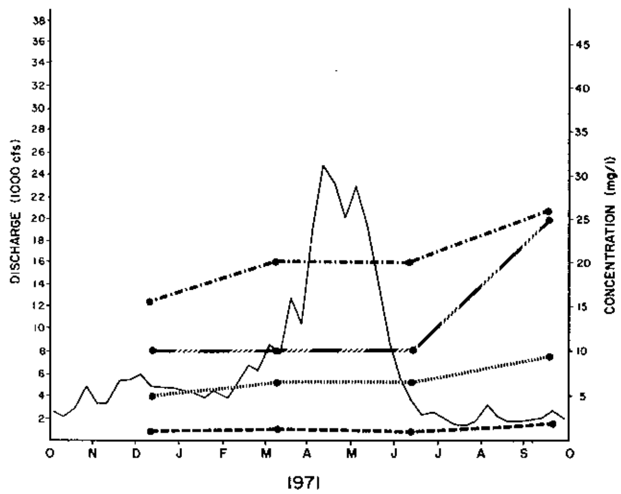


Figure C3-7a
1968-1970 Calcium, Magnesium, Bicarbonate, Hardness Water Quality Station 3

Merrimack River Diversion Study

- Calcium
- Magnesium
- Bicarbonate
- Hardness
- Discharge



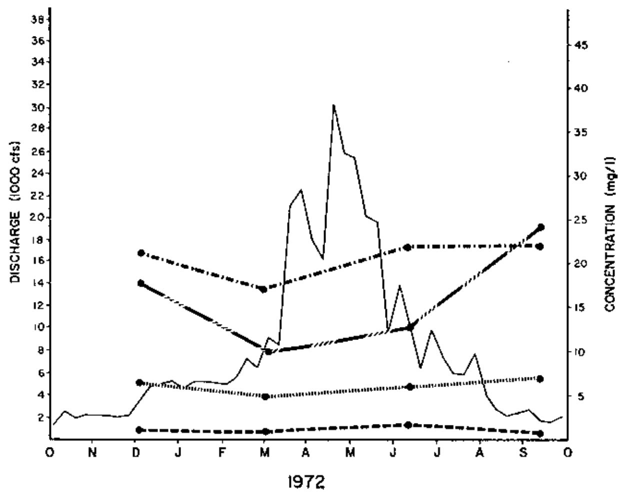
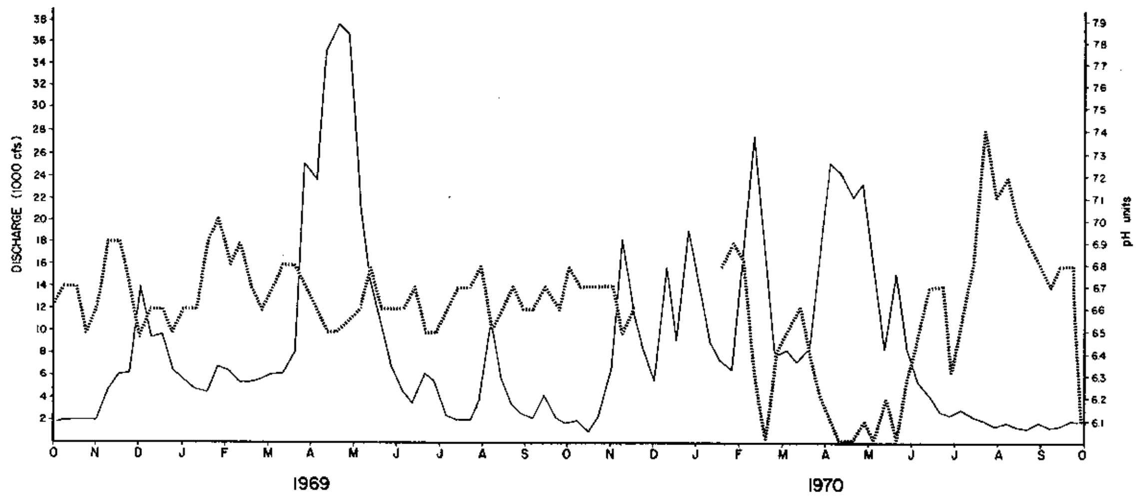
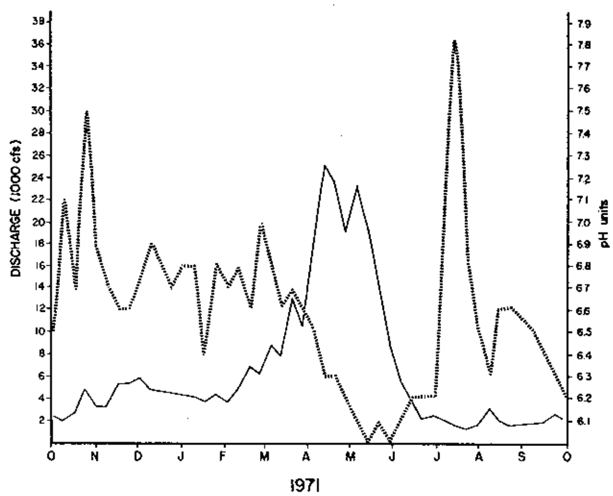


Figure C3-7b
1971 -1972 Calcium, Magnesium, Bicarbonate, Hardness
Water Quality Station 3

Calcium
Magnesium
Bicarbonate
Hardness
Discharge

Merrimack River Diversion Study



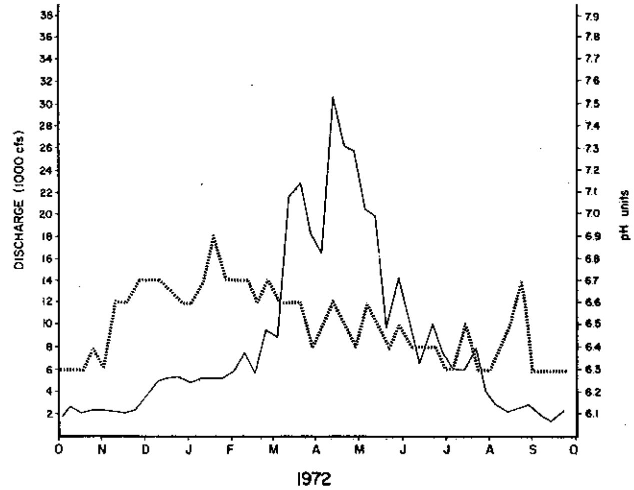


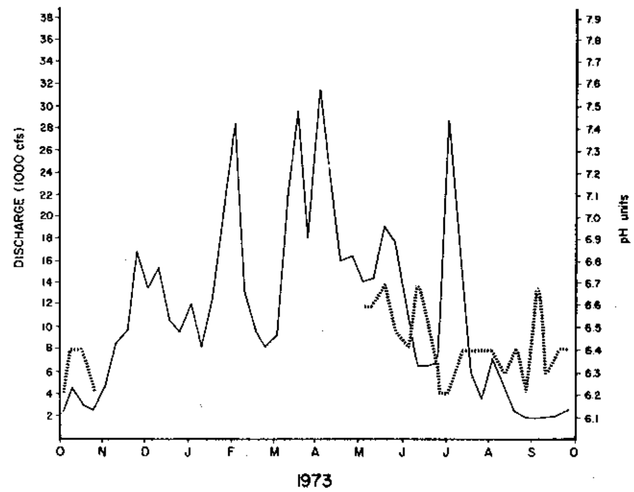
Note: Plots based on continuous monitoring

Figure C4-1a
1969-1971 pH
Water Quality Station 4

pH
Discharge

Merrimack River Diversion Study



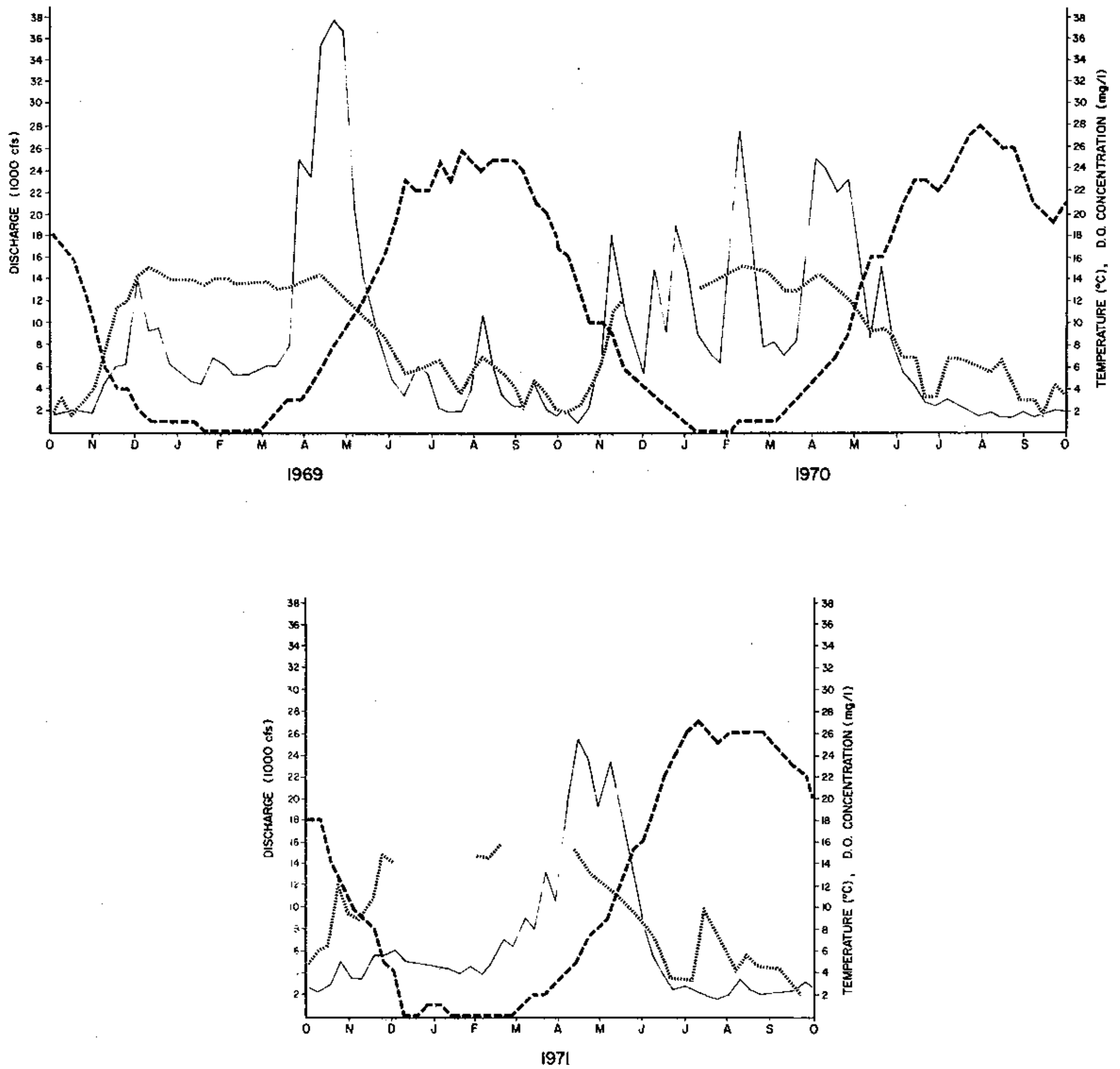


Note: Plots based on continuous monitoring

pH
Discharge

Figure C4-1b
1972 - 1973 pH Water Quality Station 4

Merrimack River Diversion Study

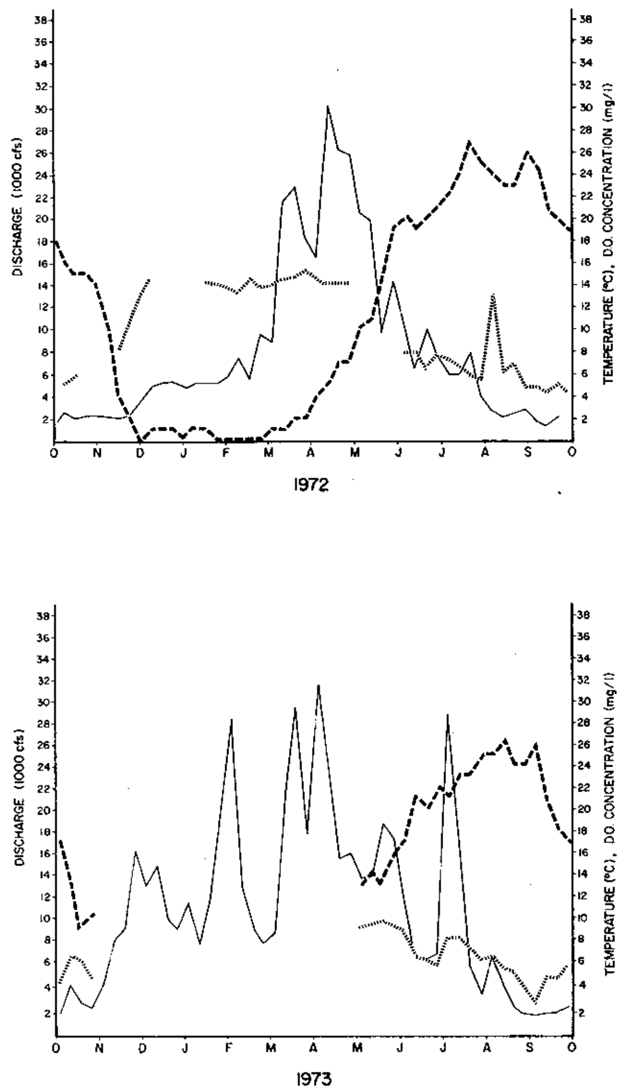


Note: Plots based on continuous monitoring

Figure C4-2a
1969-1971 Dissolved Oxygen Temperature
Water Quality Station 4

Merrimack River Diversion Study

Dissolved Oxygen
Temperature
Discharge

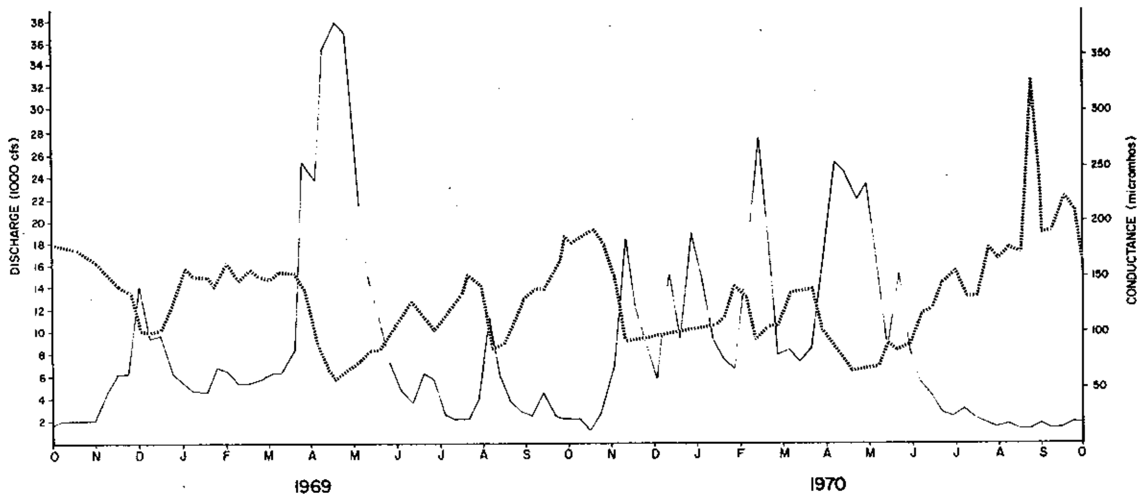


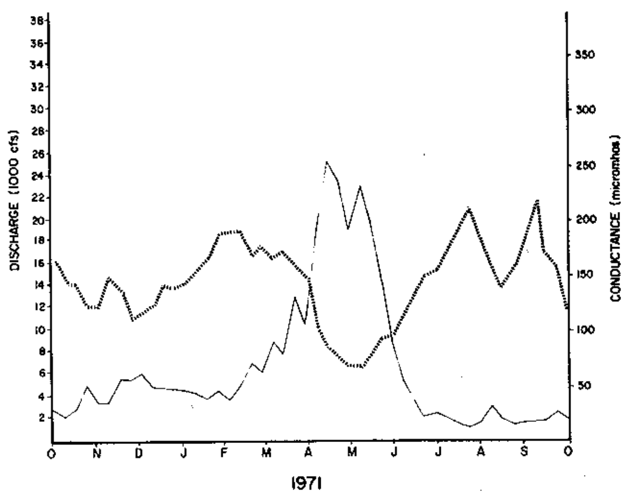
Note: Plots based on
continuous monitoring

Figure C4-2b
1972-1973 Dissolved Oxygen Temperature
Water Quality Station 4

Merrimack River Diversion Study

Dissolved Oxygen
Temperature
Discharge



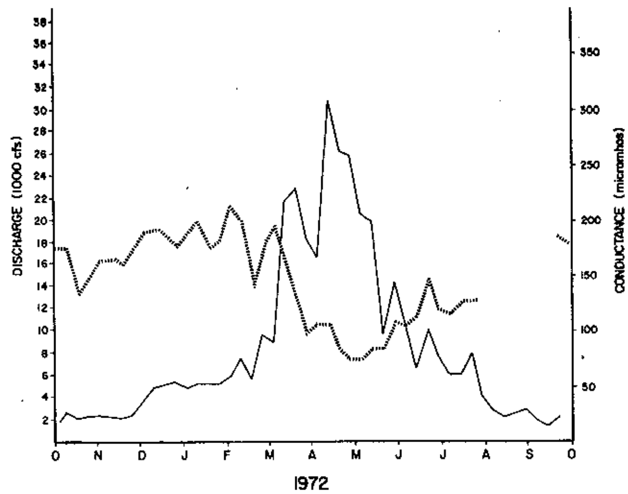


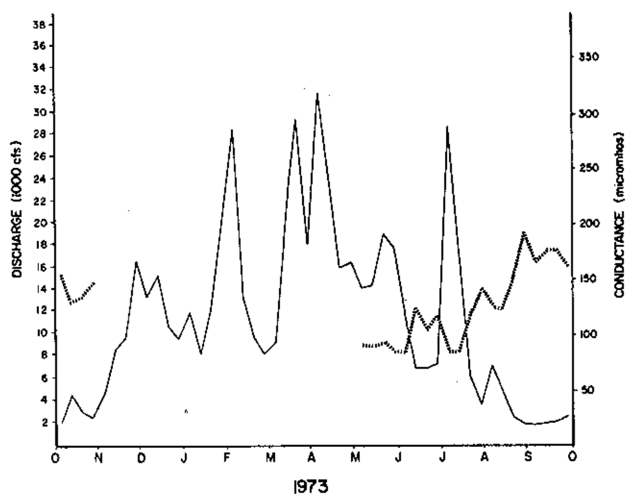
Note: Plots based on continuous monitoring

Figure C4-3a
1969-1971 Specific Conductance Water Quality Station 4

········ Specific Conductance
——— Discharge

Merrimack River Diversion Study





Note: Plots based on continuous monitoring

Figure C4-3b
1972 - 1973 Specific Conductance Water Quality Station 4

Specific Conductance
Discharge

Merrimack River Diversion Study

APPENDIX D

ANADROMOUS FISH HISTORIES

TABLE OF CONTENTS

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D.1 ALEWIFE, *Alosa pseudoharengus*

The Run

Alewives ascend coastal streams each spring from the Gulf of St. Lawrence to North Carolina. The timing of the run, a factor governed by water temperature, varies slightly from year to year. (Belding, 1921) (Kissil, 1970) Alewives commence running upstream when waters have warmed to 12°C. (Meister, personal communication) In streams which discharge into Massachusetts Bay, alewives first appear in late March or early April. (B+S) In Massachusetts, the greater part of the run occurs from the middle of April to June 1. (Belding, 1921)

There is a paucity of information on the factors which influence the migration and homing abilities of alewives. Studies of the factors affecting the migration of anadromous fish are usually confined to the shad and salmonids. Belding (1921) states that he believes that alewives spawn in their natal streams.

Alewives exhibit a rheotactic response to current; their progress is continuous in a rapid flow, and no appreciable headway is made in quiet waters. (Belding, 1921) Bigelow and Schroeder state that alewives, "... are much more successful than shad in surmounting fishways of suitable design." Adults ascend rivers in groups of 5 to 10 fish, more if the run is particularly heavy. (Belding, 1921) Alewives are known to ascend both large rivers and streams which are only a few inches deep (B+S, 1953)

Spawning of the Alewife

Alewives spawn in ponds and in the sluggish sections of streams. (B+S, 1953) Ponds at the heads of tributary streams are common spawning grounds. (Belding, 1921; McCann, unpub.) Unlike the shad, alewives are not able to spawn in slightly brackish water. To deposit their eggs, they require water with less than 1% salt. (Davis et al, 1970) The preferred stream substrate is a fine sand or mud bottom.

The eggs are demersal and adhesive, sticking to brush, stones, and sand (Belding, 1921; McCann, unpub.; B+S, 1953) Approximately 60,000 to 100,000 eggs are spawned annually per female. (B+S, 1953; Scott and Crossman, 1973) Belding (1921) states that most alewife production in the Merrimack River occurs in New Hampshire.

Various water temperatures have been recorded as being suitable for successful spawning. Bigelow and Schroeder (1953) state that spawning takes place between 12°8 and 15.6°C. Alewives spawn in the Connecticut River at temperatures between 7.2° and 22.2°C. (Essex Marine Lab, 1972) Greeley (1938) states that the upper temperature limit in a landlocked population was 22.8°C. Spawning in Massachusetts waters occurs between 12.8° and 21.1°C. (Belding, 1921)

Downstream Movement of Adults

Adult alewives return to saltwater immediately after spawning (B+S, 1953) Frequently while moving to salt water, spent fish pass gravid fish which are ascending to a spawning ground (B+S, 1953) During the freshwater migration, adult alewives do not eat, but upon reaching brackish water, they resume feeding. (B+S, 1953) Their diet is composed primarily of zooplankton.

Egg Development

The rate of egg development is dependent principally upon water temperature. Thirteen days are required to hatch eggs at 7.8°C. (Edsall, 1970) Belding (1921) states that in Massachusetts the majority of juvenile alewives remain on their breeding grounds until September 1. By mid-autumn of their first year, juvenile alewives are in the estuary of their home river.

Like other juvenile fish, young alewives are susceptible to high temperatures. 15 mm larvae die when exposed for 50 to 100 minutes to 30° (Marcy, 1971). Minimum survival occurs at 28°C. (Edsall, 1970)

Kissil (1970) determined that one young alewife migrated seaward for every 80,000 eggs spawned. This is a 99.99987% freshwater mortality of eggs and juveniles. Because he estimated that 48,000 to 360,000 eggs are spawned per female, Kissil concluded that 2.88 young are produced per female per year.

Alewives become sexually mature at 3 or 4 years of age. At this time they return to freshwater to produce a new age class of alewives.

D.2 BLUEBACK HERRING, *Alosa aestivalis*

Except for coloration differences and temperature requirements the Blueback Herring and Alewife are nearly identical. The Blueback herring ranges along the Atlantic coast between northern Florida and southern New England (B+S, 1953) It is commonly found in the Merrimack River Estuary (Jerome et al , 1965) The Blueback Herring enters freshwater to spawn when water temperatures are 14°-15° C.(personal communication with Al Meister) Bigelow and Schroeder (1959) state that spawning for this species occurs when waters have warmed to 21.1-24°F. Because the breeding habits and requirements of the blueback are similar to those of the alewife (B+S) (Personal communication with Meister),the information in the life history of the alewife, except for temperature requirements, will be considered applicable to the blue back herring.

D.3 ATLANTIC SALMON, *Salmo salar*

Probably the better known anadromous fish are the various species of salmon of the genera *Oncorhynchus* and *Salmo*. Historically, Atlantic salmon, *salmo salar*, made annual spawning runs up suitable rivers ranging from Labrador to the Housatonic River in Connecticut (B+S, 1953). Today, the number of rivers ascended by the Atlantic salmon is comparatively small. Pollution and the erection of dams are the principal causes for the depletion of stocks of *Salmo salar*. The species is considered by some to be endangered. (Netboy, 1968) (Miller, 1972)

Homing

Aside from the commercial importance and the palatability of salmon, the chief interest in this species concerns its remarkable homing ability. Extensive research has resulted in the general acceptance of the Parent Stream Theory. This theory proposes that a salmon spawns in that stream in which it developed during juvenile stages. A determination of the means by which salmon are able to navigate from their oceanic feeding grounds to their natal streams has been the object of much research. Literature on this subject is voluminous. The acute olfactory sense is thought to be the principal means by which salmon are able to identify their natal stream. Each stream and river is believed to have its own characteristic odor which is distinguishable to a homing salmon. An orientation to the sun is thought to aid in navigation while salmon are in open sea. (Hasler, 1966) For more information on theories and research pertaining to the homing ability of salmon, the reader is referred to Hasler (1966) and Jones (1968).

The Spawning Run

It has long been known that freshets, sudden increases in stream discharge, have a stimulating effect on the swimming behavior of freshwater fish. When exposed to increased flow, many species exhibit rheotaxis; that is, they react by swimming into the current. It is believed that this response is an attempt to compensate for displacement in the river. (Huntsman, 1945)

Salmon congregate in harbors and estuaries prior to entering freshwater. Freshets are usually the stimulus which causes the commencement of the freshwater run. (Huntsman, 1945; Davidson et al, 1943; Hayes, 1953; Alabaster, 1970) Movement upstream usually begins as a freshet subsides. Coston et al (1936) have personified salmon in stating, "Without a freshet, salmon know from instinct that there isn't sufficient water in the river to provide passage upstream."

Hayes (1953) experimented with artificial freshets in an attempt to upgrade Atlantic salmon fishing in the LaHave River, Nova Scotia. He released impounded water in variable amounts throughout the summer months of 1949-1951. Summer discharge in the LaHave River is usually between 200 and 300 cfs; spring discharge is considerably higher. Those artificial freshets lasting 6 to 8 hours which tripled discharge generally succeeded in initiating a run of salmon. Freshets which raised river discharge from approximately 1,000 to 1,400 cfs were inconsequential. Other freshets which did not at least double the discharge had no effect on salmon migration.

The success of artificial freshets was dependent upon onshore winds, suitable tides, and the presence of salmon in the estuary. Hayes (1953) states that, "There is also evidence that fairly strong onshore winds, approaching 20mph, induce salmon to concentrate in the river estuary and eventually ascend. Peaks in the tidal cycles representing daily increasing differences between high and low tides seem to be effective in concentrating salmon in the estuary and initiating a run into freshwater. Large natural freshets can initiate a major run of fish into the river provided the winds and tides are not favorable. In cases where these other two factors were not favorable, no run occured".

The results of other research indicates that factors other than freshets may be involved in the initiation of freshwater migration. Further experimentation by Hayes (1953) involved releasing sustained flows of 400 cfs for 24 days during the run season (June-July). This stimulated the bulk of the run for 1951. Hayes (1953) concluded that increased flow (without freshets) due to natural rainstorms is an adequate stimuli for the initiation of freshwater migration.

Freshets stimulate pink salmon, *Oncorhynchus gorbuscha*, to commence their freshwater migration, but in the absence of freshets, pink salmon in McClinton Creek, Alaska begin their run upon reaching sexual maturity (Davidson _et al_, 1943) The salmon observed in this study spawned typically in the first few miles of the river, however, a delay in initiating the run for those salmon which typically ascend rivers for long distances could result in the ripening of sexual products long before the salmon have reached a suitable spawning ground. This could result in reduced productivity.

Stream flow is important in determining the size of a run of salmon. Oglesby _et al_ (1972) report that in years of low discharge, the spawning run of salmon is delayed. This delay causes reduced productivity.

Salmon leave saltwater to spawn in freshwater throughout spring and summer. The first Gulf of Maine salmon to enter rivers do so in March and April. (B & S, 1953) Others leave salt water in summer and early fall. (Newell _et al_, 1963) (Cutting, 1966) Most migrating adults are 3 to 5 years old, and a few are older. Adults which spawn after only 1 year at sea are 3 years old, and are referred to as grilse. Older salmon which have spent at least 2 years at sea predominate in the spring runs; grilse run usually during the summer months. (B & S, 1953) The exact timing of a run is variable, dependent upon the river discharge, i.e., freshets (B & S, 1953).

Various chemical and physical factors can affect the migratory movements of salmon. Salmon are sensitive to temperature, pH, dissolved gas concentrations plus the concentrations of various pollutants such as dissolved heavy metals. Small amounts of zinc or copper can cause an avoidance reaction in migrating salmon. (DeCola, 1970)

Hayes (1953) noted that the timing of a salmon run is not temperature dependent. Elevated temperatures, however, can seriously affect migration. Maine salmon will not enter rivers when water temperatures exceed 23°C. (DeCola, 1970) Temperatures above 20°C contribute to the mortality of salmon. (DeCola, 1970) The National Technical Advisory Committee recommends that, for the migration of salmonids, temperatures should not exceed 20°C. (DeCola, 1970)

Limited or excessive concentrations of dissolved gases can proscribe salmon migration. Reductions in dissolved oxygen concentrations results in reduction of swimming speeds. (Doudoroff, _et al_, 1970) The National Technical Advisory Commitee recommends that for rivers used only as migratory routes, a minimum of 5ppm O_2 can be considered adequate, if exposure is for no longer than 6 hours. For periods longer than 6 hours, migrating salmon require a minimum concentration of 6ppm O_2.(DeCola, 1970) Salmon are able to withstand relatively high levels of dissolved CO_2, however, increased CO_2 concentrations cause an increase in dissolved oxygen requirements.(DeCola, 1970) The National Technical Advisory Committee recommends that concentrations of dissolved CO_2 should not exceed 25ppm.(National Technical, 1970)

The pH range which is suitable for Atlantic salmon is 5 to 8.5. Maine salmon are typically found in waters with pH ranging from 5 to 7.(DeCola, 1970) Healthy populations of fish usually occur in waters with pH ranging between 6.5 and 8.5.(DeCola, 1970)

Concerning water hardness, DeCola (1970) states, "Atlantic salmon of North America are typically found in very soft water with a total hardness of less that 20ppm."

Salmon are rheotactic. During migration upstream, salmon will persist in swimming while exposed to a current. (Huntsman, 1948) Research indicates that a minimum velocity of 1-2 f.p.s. is required to sustain movement upstream. (Weaver, 1963) (Gavley, 1966)

Spawning of *Salmo salar*

Atlantic salmon spawn over sandy or gravel bottoms in riffle areas of cold streams. Spawning in Gulf of Maine streams occurs in late October and early November (B & S, 1953) when water temperatures are between 4.4 and 5.6°C.(DeCola, 1970) (McCann, unpub.) Jones (1968) states that Atlantic salmon spawn over a temperature range of 5.5-10°C.

Nesting areas of salmonids are referred to as "redds." A female creates several depressions in the gravel in shich she deposits her eggs for fertilization.(Cutting, 1966). These depressions are referred to as "egg pits." After fertilization, the eggs are buried by the female under 5 to 10 inches of gravel where they will remain until the following spring.(McCann, unpub.) (Cutting, 1966) A ten pound female deposits approximately 8,000 eggs.(Cutting, 1966)

Spent Fish

Spent salmon are referred to as "kelts" or "black salmon." Salmon at this stage are in an emaciated condition due to previous physical exertion and lack of feeding during the movement upstream. Many kelts die after spawning. In the smaller rivers, kelts move down to the sea immediately after spawning. In larger rivers, those kelts, that do not die, remain in the rivers until the following spring.

Egg Development

Eggs remain buried in their redds until the following spring. Hatching success is dependent principally upon adequate temperatures and an abundance of dissolved oxygen.

The respiratory rate of salmon embryos increases as development proceeds.(Hayes, 1963) The greater oxygen demand by developing embryos occurs just prior to hatching.(DeCola, 1970) At 6° and 9°C, Atlantic salmon eggs just before hatching require dissolved oxygen concentrations of 6ppm and 7 ppm respectively.(DeCola, 1970) A high velocity of water flowing over the redds is needed to insure an adequate supply of oxygen (DeCola, 1970) (Oglesby, 1972).

For successful hatching, developing embryos require cold stream water. Temperatures between .5 and 7.2°C are considered adequate for normal egg development.(DeCola, 1970) Temperatures which exceed 9°C are adverse to the production of healthy salmon fry.(DeCola, 1970)

Hatching occurs in April or early May.(B & S, 1953) A newly hatched salmon, referred to as an alevin, remains under the gravel until its yolksac is absorbed. A newly hatched alevin is 15 to 18mm long, and requires about 6 weeks to absorb its yolksac.(B & S, 1953)

Juvenile Development

After absorption of the yolksac, the young salmon, now referred to as a "parr," wriggles free from its gravel hiding place. Parr remain in freshwater for a variable amount of time. Usually they remain in their natal streams for 2 summers and 2 winters, descending to the ocean during their third summer (B & S, 1953; Newell, *et al*, 1963)

Tagging studies reveal that parr have specific homes in their natal streams.(Saunders and Gee, 1964) Parr usually remain in specific pools or riffle areas during the summer months. Huntsman (1945) states that some parr wander considerable distances in their homestreams. He reports that migrating parr populate tributaries in the lower Margaree River, Nova Scotia. These parr descend into brackish water and then ascend tributaries previously absent of salmon. During the months of autumn, parr movement is frequent, and can be in either an upstream or downstream direction (Saunders and Gee, 1964) (Meister, 1962)

Normal growth of salmon parr occurs at temperatures between 15° and 19°C.(DeCola, 1970) The acclimated temperature determines the lethal temperature for parr. Huntsman (1942) has noted that salmon are able to withstand temperatures as high as 32°C, however, temperatures in excess of 27°C cause parr to leave their homes and drift downstream in search of cooler waters. (DeCola, 1970) DeCola (1970) states that at an acclimation temperature of 13°C, 50% mortality of parr occurs within 6 hours at 26.7°C.

Smolts

When Atlantic salmon parr are in their third spring, they are usually ready to begin their descent to the sea. At this time, they are 5 to 6 inches long. (B & S, 1953) During their descent, the juvenile salmon, now referred to as "smolts", turn silvery in color. Bigelow and Schroeder (1953) state that in the Gulf of Maine, most smolts migrate in June and July. In considering the timing of smolt movement, Meister (1962) noted that peak movement is generally observed in May and early June. He states that emigration does occur in autumn, but that most autumn migrants are precocious members of the year class which will descend during the following spring.

Water temperature is a major factor determining the timing of smolt migration. Studies on sockeye salmon indicate that the timing of smolt migration is directly related to water temperature.(Foerster, 1937) Movement generally commences when spring water temperatures reach 4.5-5.5°C.(Foerster, 1937) Freshets also induce smolts to begin their downstream movement.(Huntsman, 1945) Allen (1944) states that rises in water level (freshets) and optimum temperatures are the two criteria which determine the timing of smolt movement.

Foerster (1937) studied the migration of sockeye salmon juveniles which use Cultus Lake, British Columbia as a nursery habitat. He observed that cessation of smolt movement out of Cultus Lake occurs when the temperature at the stream outlet exceeds 10°C. Foerster believes that a temperature barrier is created at the outlet which causes some juveniles to remain in the lake until the following spring.

Movement out of natal streams by Atlantic salmon smolts also ceases when temperatures exceed 10°C.(DeCola, 1970) Juvenile salmon, however, are able to withstand much higher temperatures. Huntsman (1942) noted that adult salmon succumbed to high temperatures before salmon parr. He states that adult salmon succumb at approximately 30.5°C, and that parr die at 32.9-33.8°C. The temperature of acclimation determines the exact lethal temperature limit.

Predation by birds is considered to be the primary cause of mortality in smolts and larger parr. (Huntsman, 1938) (White, 1939) Belted kingfishers and American merganzers are the two most common predators of juvenile salmon. Elson (1957) states that smolt production ranges between 1 and 5 smolts per 100 square yards of nursery habitat. The exact number depends upon the fishing pressure by predatory birds. Newell and Newell (1963) believe that the presence of forage fish, acting as buffer species, and a limited number of predatory birds in New Hampshire should result in the production of 3 smolts per 100 square yards of nursery habitat in the Merrimack watershed.

Descent down a home river requires a variable amount of time. Impoundments can significantly increase the time required by smolts to reach the ocean.(Saunder, 1960) (Raymond, 1968) Discussing the results of tagging studies on Pacific salmon in the Columbia and Snake Rivers, Raymond (1968) noted that passage of smolts through a large impoundment occurred at a velocity which was 1/3 of the normal rate of descent. He states that the erection of other dams on the Snake and Columbia may result in a much longer period of downstream migration. Raymond believes that this increased time in descent might affect smolt survival.

Pacific salmon smolts progress slowly through an estuary as they proceed seaward.(McInerney) McInerney (1964) has investigated the movement of smolts through estuaries, and believes that salinity gradients are a means of guiding smolts out of the estuary. Experiments indicate that salmon exhibit a temporal progression of changes in salinity preference.(McInerney) McInerney believes that this mechanism aids smolts in navigating in unfamiliar, spacious estuaries.

While in the ocean salmon grow very quickly. After one year at sea, salmon usually attain 16 inches in length. Some salmon spawn as grilse, but most wait until they have spent 2 years at sea before entering rivers to reproduce.

D.4 SHAD, *Alosa sapidissima*

Each spring, numerous streams along the coasts of North America abound with American shad, *Alosa sapidissima.* (Wilson) The sexually mature fish leave their ocean habitat temporarily to spawn in suitable freshwater rivers and streams. Western Atlantic populations spawn in rivers ranging from the St. John River, Florida to the St. Lawrence River, Canada .(Mansueti and Kolb, 1953), (Bigelow and Schroeder, 1953)

Timing of the Run

The timing of the spawning run is closely governed by water temperature . (Bigelow and Schroeder, 1953), (Essex Marine Lab, 1972) Shad ascend when river temperatures are between 5° and 23°C. (Walburg, 1960) Tagging studies in the Connecticut River (Essex Marine Lab, 1972), revealed that the first shad enter that river when the water temperature is between 4.4 and 7.2°C; however, the majority of spawning fish commence running at higher temperatures. Various authors cite differing water temperatures occurring during the peak of the spawning runs, i.e. 13.3° to 16.1°C (Walburg, 1960); 10° to 12.8°C (Bigelow and Schreoder, 1953); 10° to 15°C (Essex Marine Lab, 1972); 13.3 to 18.9°C (Leach, 1925 in Mansueti and Kolb, 1953). Shad entering the Connecticut River at temperatures higher than 14°C are found to have a higher mortality rate. (Leggett, 1969 in Essex Marine Lab, 1972) It is thought that the higher mortality of shad spawning in southern streams is due to high temperatures.(Essex Marine Lab, 1972)

The date on which migration commences in a particular river is related to the latitude of the river. Migration in the St. Johns River, Florida begins in mid-November; the greatest number appearing in February .(Mansueti and Kolb, 1953) In Georgian rivers, shad ascend from January to March .(Bigelow et al, 1953) (Mansueti & Kolb, 1953) Shad are most numerous in the Potomac in April and early May.(Mansueti and Kolb, 1953), (Bigelow and Schroeder, 1953) The Connecticut River has its most abundant runs during the latter half of May.(Mansueti and Kolb, 1953) Bigelow and Schreoder state that for the Merrimac River... "the first shad appear (or did) late in April, with the main run in May and June; the first ripe females are caught the last week in May and they begin to spawn about June 1, most of them doing so during that month, a few in July, and possibly an occassional fish as late as August." McCann (unpub.) states that peak spawning runs in Massachusetts occur during the last two weeks of May and the first two weeks of June. The spawning run in the Miramichi River, New Brunswick commences in late May. (Mansueti and Kolb, 1953)

Factors Affecting Migration

Shad usually return to their natal streams to spawn. (Essex Marine Lab, 1972) Shad first spawn when they are 4 to 5 years old. Those adults which survive the strain of spawning return annually to spawn again. (Walburg, 1960) (Essex Marine Lab, 1972) (Bigelow & Schroeder, 1953) The oldest shad in the Gulf of Maine rivers are 8 or 9 years old. (Bigelow & Schroeder, 1953) Shad are plankton feeders, eating primarily pelagic crustaceans. (Bigelow & Schroeder, 1953) During the upstream migration shad cease feeding. Factors contributing to the homing ability of anadromous fishes have been studied extensively, but it is not known how shad identify their home rivers. Factors which may determine migratory movements of anadromous fish are odor (Hasler and Wisby, 1951) (Craigie, 1926) (Jones, 1968) (Hara, 1970), CO_2 gradients (Powers 1939, 1941), and salinity gradients (Merriman et al, in Essex Marine Lab, 1972). After the home river is located, the acute olfactory sense is thought to contribute largely to a fishes ability to find its natal stream. (Mansueti and Kolb, 1953) Prior to migration into freshwater, salmon congregate in estuaries. It is believed that strong freshets stimulate the fish to move upstream. (Huntsman 1945, 1948, 1950) Huntsman (1945) indicates that shad behave similarly to salmon in relation to freshets. Additional information on freshets is in Appendix II, Spawning of Salmon.

Shad runs extend several hundred miles upstream. They are known to ascend 375 miles up the St. Johns River, Florida, and 200 miles up the St. Johns River, New Brunswick. (Bigelow & Schroeder, 1953) Historically, shad runs in the Merrimac River extended 125 miles to Lake Winnepesaukee. (Bigelow and Schroeder, 1953)

In studies on the Connecticut River, Essex Marine Lab states,

> "Leggett and Whitney found that the timing of the shad run at Holyoke was temperature dependent. From 1955 to 1969, they noted a positive correlation between the time of median shad passage and the time the temperature first exceeded 65°F ($r = 0.748$, d.f. = 13, $p<0.01$). They also noted that the peak of the run occurred within a narrow temperature range (64 to 71°F), and that 86.6% of the observations were within the 66 to 70°F range."

This study would seem to indicate that upstream progress of shad is temperature dependent. Huntsman (1946) reports that great fish kills, including many shad, occur when river temperatures reach 31°C.

Spawning of Shad

Physical and chemical requirements for spawning include considerations of substrate, velocity and depth of water, temperature, dissolved oxygen, and salinity tolerances. Spawning occurs over sandy or pebbly bottoms in 3 to 30 feet of water. (Walburg, 1960) In some rivers, shad prefer definate spawning areas such as sandy flats located below the mouths of creeks. (Mansueti and Kolb, 1953) Walburg (1953) states that spawning occurs normally in waters with velocities of 1 to 3 f.p.s. Brager (1972) reports that Florida shad spawn in currents of 1 to 1 1/2 f.p.s. Shad spawn from the limit of brackish water to several hundred miles upstream. (Walburg, 1960) Juvenile shad have a salinity tolerance of 7.5 0/00. (Leim, 1924) Successful spawning requires a dissolved oxygen content of 5 ppm. (Walburg, 1960) Connecticut River shad are known to spawn between 10.5°C and 22.8°C. Spawning at 26.7°C is said to result in nonviable eggs. (Essex Marine Lab, 1972) Massmman & Pachico (1957) stated that shad do not spawn until water temperatures are above 12.2°C.

Shad are prolific spawners; the number of eggs produced is directly related to the size and age of the female. Populations of shad spawning in waters south of North Carolina have more eggs per ovary. (Leggett, (1969) in Essex Marine Lab, 1972) This phenomenon is an adaptation to survival in warm waters, as southern populations die soon after spawning. In the Connecticut River the average fecundity is estimated to be 148,710 eggs per female (Watson (1970) in Mass Fish and Game project #AFS 7-1) Studies on the Hudson River reveal shad fecundity to be 116,000 to 468,000 eggs per female. (Oatis F&G in Mass. Fish & Game project #AFS 7-1)

The eggs are nonadhesive and semiboyant, a characteristic which causes them to gradually sink in nonturbulent waters (McCann, unpub.), (Bigelow & Schroeder, 1953) Eggs preserved in 5% Formalin sink 2.4 feet per minute at 25°C. (Walburg, 1960)

Migration of Spent Fish

Adult shad in northern rivers return to salt water immediately after spawning. (Bigelow and Schroeder, 1953) The spent fish, referred to as "down-runners" or "racers", are in an emaciated condition. This is due to physical exertion and not feeding during migration upstream. They resume eating on their descent, becoming quite fat by the time they reach salt water. (Bigelow and Schreoder, 1953) (Mansueti & Kolb, 1953) Due to a low specific gravity following spawning, "racers" may swim in surface waters (Mansueti and Kolb, 1953). These fish have been observed in the Kennebec River as early as June 20th. The remaining spent fish in the Kennebec River descend throughout July. (Bigelow 7 Schroeder, 1953) It can be assumed that down-runners occur in the Merrimack River during June and July.

Egg Development

Normal egg development is dependent upon suitable water temperature. Egg development within the ovaries proceeds slowly between 12.8°C and 18.3°C. (Essex Marine Lab, 1972) (Walburg, 1960) In warmer waters, 20° to 25°C, egg development proceeds more rapidly and is soon complete. (Essex Marine Lab, 1972) At these higher temperatures, some of the eggs produced are nonviable and invariably above 25°C "rotten ripe" eggs are produced. (Mansueti and Kolb, 1953) After fertilization, egg development occurs between 7.8° and 26°C. (Leim, 1924) Bigelow and Schroeder (1953) state that eggs require 12 - 15 days to hatch at 11.1°C (52°F), and 6 - 8 days at 17.2°C (63°F). Leim (1924) found that 7°C stopped egg development; 22°C caused considerable abnormalities, and that 27°C was definitely unsuitable. Leach states that the minimum and maximum for successful hatching are 12° and 19°C respectively. (Walburg, 1960) Fungus and smothering by layers of silt or mud are the most serious dangers to proper egg development. (Walburg, 1960) (McCann, unpub.)

Development of Larvae and Juveniles

Upon hatching, shad larvae are 9 - 10 mm (Bigelow and Schroeder, 1953) The yolksac is absorbed in 5 to 7 days. (Walburg, 1960) There is little information on the physical and chemical requirements of juvenile shad. Shad, which are 8 to 11 cm in length, have a minimum lethal level of dissolved oxygen of 0.6 to 3.66 ppm at temperatures between 17° and 19°C (Doudoroff, 1970) Tagatz states that for 6.7 cm shad, lethal levels of dissolved oxygen are 0.9 to 1.4 ppm at 21° to 23°C. (Doudoroff, 1970) These D.O. requirements were derived from controlled laboratory experiments. They do not reflect the higher concentrations needed by fish surviving in their natural habitat. Juvenile shad are unable to withstand water temperatures of 32°C. (Moss, 1970) Juvenile fish are more susceptible to high temperatures than adults. Experiments by Essex Marine Lab (1972) reveal that juvenile shad are unable to withstand temperatures in excess of 27.8°C.

Juvenile shad remain in their natal rivers until autumn of their first year. (Bigelow and Schroeder) (Mansuete & Kolbo). During their first summer, they disperse in the river. (Leim, 1924) The youngest are found near the spawning grounds and the older juveniles are farther downstream. (Walburg, 1960) Temperature and freshets are believed to stimulate downstream migration of juvenile shad. (McCann, unpub.) Movement begins after water temperatures have decreased to 15.5°C. (Walburg, 1960) Migrant juveniles are 1 1/2" to 4 1/2" upon reaching salt water. (Bigelow and Schroeder, 1953) The young shad mature in salt water, returning to fresh water in 4 or 5 years to produce a new age class of *Alosa sapidissima*.

D.5 SMELT, *Osmerus mordax*

The Run

Smelt run annually in streams, ranging from eastern Labrador to New Jersey; and occassionally they are found in Virginia. (Bigelow & Schroeder, 1953) Like salmon and alewives, smelt have established landlocked populations in certain lakes. Along the western Atlantic coast, *Osmerus mordax* is the first anadromous species to appear each spring. Bigelow and Schroeder (1953) state "Most of them winter between the harbor mouths and the brackish water farther up; the maturing fish commence their spawning migration into fresh water as early in the spring as the ice goes out of the streams and the water warms to the required degree." McKenzie (1964) states that smelt do not enter the Miramichi River, New Brunswick until the ice has cleared, and the water has warmed to 4 - 5°C. In the Miramichi Movement into tributaries, where spawning takes place, does not occur until temperatures rise to 6 - 7°C. (McKenzie) In the Weir River, Massachusetts, smelts first appear on their spawning beds at temperatures of 4.4 - 5.6°C. This occurs between the first and last week in March. (Bigelow and Schroeder) Bigelow and Schroeder state that spawning of eggs in Massachusetts occurs primarily between 10 and 14°C and is over by mid May.

Smelts do not ascend rivers for great distances as do other anadromous fish. (Bigelow and Schroeder) Kendall (1926) states that smelts do not ascend much beyond the zone of brackish water. Some spawn in slightly brackish water, although high salinities kill the eggs. (Bigelow and Schroeder, 1953) (Kendall, 1926) Smelts ascend both small coastal streams and large rivers, but in the latter case they divert into smaller tributary streams before spawning. (Kendall, 1926) In the Miramichi River system, smelts venture only a short distance above the head of tide. Less than 20% of this watershed is utilized by smelt. (McKenzie, 1964) One of the more distant spawning grounds in the Miramichi watershed is approximately 18 miles upstream in a tributary of the Bartiboy River. (McKenzie, 1964)

Spawning

Smelt spawn over bottoms composed of mixtures of gravel and small amounts of sand. (Langlois, 1935) Eggs are laid without construction of nests in shallow sections of streams; few, if any, are laid in waters deeper than 18" to 20". (Rupp, 1965) Eggs are demersal and adhesive, sticking to stones, sticks, weeds or anything else that they may contact. (Bigelow and Schroeder) (Rupp, 1965)

Smelts are nocturnal spawners (McKenzie) (Bigelow and Schroeder), (Kendall), requiring 2 - 3 hours per school to spawn. (Rupp, 1965)

For their size, smelt are very prolific. A 2 ounce female produces between 40,000 and 50,000 eggs. (Bigelow and Schroeder) Langlois (1935) reports that 185 - 195 mm females yield an average of 25,102 eggs. McKenzie (1964) reports that the number of eggs spawned per school is not indicative of the number of larvae produced by the school. He found that 487 eggs/ft^2 resulted in the survival of 3.6% larvae, whereas 180,200 eggs/ft^2 had a survival rate of .03% larvae. After spawning adults reutrn immediately to salt water. (Bigelow and Schroeder)

Development of Eggs & Juveniles

Incubation time for smelt eggs are 19 - 20 days at temperatures between 5 and 8°C; and 10 days at 15°C. (Hoover in Essex) (McKenzie) The upper lethal temperature tolerance of smelt eggs is between 21.5 and 28.5°F. (Huntsman & Sparks in Essex)

Larvae are 5 mm long when hatched. (McKenzie, 1964) Bigelow and Schroeder (1953) state that juveniles attain 4.5 to 7 cm by late autumn. During their first winter, juveniles are 6 - 10 cm in the Miramichi estuary. (McKenzie, 1964)

Little information is available on the months when juvenile smelt descend rivers to the sea. Bigelow and Schroeder (1953) state that it is probably early in their first summer. Smelt remain in the estuaries and ocean for 2 years before returning to freshwater to spawn. (Bigelow and Schroeder)

D.6 STRIPED BASS, *Roccus saxatilis*

The striped bass, *Roccus saxatilis*, ranges along the Atlantic coast between the St. Lawrence River and the Gulf of Mexico. (Bigelow and Schroeder) It was introduced in the late 19th century to the Pacific coast where it extends from Washington to Los Angeles County, California. (Bigelow and Schroeder) In the western Atlantic it breeds in coastal streams usually between Florida and southern New England. Merriman (1941) reports capturing 3 juvenile stripers in the Parker River in Newburyport, Massachusetts. He states that this is the most northern point of recent observations of juvenile stripers. Leim (1924) reports capturing numerous juveniles in the Shubenacadie River, Nova Scotia, during the summers of 1922 and 1923. Bigelow and Schroeder (1953) cite many instances of striper being observed in the Merrimack River, but they make no mention of striper spawning there. Historically, striper spawned in many of the rivers along the Gulf of Maine.

Adult striped bass are active at water temperatures between 4.4 - 6.1°C and 21°C. (B&S) (Reney 1958) Cooler waters cause them to become sluggish and settle on the bottom or move to warmer areas. (B&S) Waters higher than 77°F contribute to mortality. (Bigelow and Schroeder)

Stripers enter freshwater to spawn each spring from April through June. (Merriman, 1941) The exact timing of the run is dependent upon the latitude of the river to be ascended. Pearson (1938) reports that freshly spawned eggs were taken between May 16 and June 8, 1931 in the lower Susquehanna River, Maryland. In the Hudson River, spawning occurs mid-May through June. (Raney, 1952) (Rathjen and Miller, 1957) Bigelow and Schroeder (1953) state that, "Any bass that may spawn in the rivers of Massachusetts, of Maine, and of the Bay of Fundy, probably do so in June;..."

Merriman (1941) estimates that 25% of female striped bass first spawn when they are 4 years old. The remaining 75% begin spawning at age 5. Most males have sexually matured by age 2, and the remaining males begin spawning when they are 3 years old.

Most stripers spawn in the first few miles beyond the influence of brackish water. (Vladykov and Wallace 1952) (Tagatz, 1961) Egg collections were conducted by Rathjen and Miller (1957) to determine the location of shad spawning areas in the Hudson River. Eggs were found only in areas where surface salinities were 1 ppm or less. Of all the eggs taken, 90.2% were found between river miles 24.1 and 35.6. The remainder were found upstream from this area. Bigelow and Schroeder (1953) state that, "The chief requirement for successful spawning is (it seems) a current turbulent enough to prevent the eggs from settling on bottom where they would be in danger of being silted over and smothered." Most of the eggs which were collected by Rathjen and Miller (1957) were in moderate to swift current and in depth of up to 200 feet.

Stripers spawn in water temperatures ranging from 14.4° to 21.7°C, with peak spawning occurring from 15.5-19.5°C. (Raney, 1952) Striper eggs collected in the lower Susquehanna River, Maryland in 1931 were taken at water temperatures of 15.5 to 21°C. (Pearson, 1938)

Stripers are very prolific. Mature females contain between 11,000 and 1,215,000 eggs. (Merriman, 1941) Average fecundity is estimated at 100,000 to 700,000 eggs. (Merriman, 1941) Bigelow and Schroeder (1953) state that large fish may contain as many as 10 million eggs.

Each striper egg contains a large oil globule, which makes it semiboyant. (B & S, 1953). The eggs move downstream without settling on the bottom provided that they are exposed to a water current. (Nichols, 1966) (Bigelow and Schroeder, 1953)

The time that eggs require to incubate is dependent upon water temperature. Incubation takes 30 hours at 21.7-22.2°C; and at 14.4-15.6°C eggs hatch in 70-74 hours. (Merriman, 1941) Raney (1952) states that 48 hours are required to incubate eggs at 64.2°F.

Newly hatched larvae are 2.5 mm long. (Raney, 1952) Within 3 or 4 weeks, juveniles are 36 mm long and have taken on the body form of adult stripers. (Raney, 1952) Rathjen and Miller's (1957) study of stripers revealed that juveniles first appear in the Hudson River during the last week in June. Juveniles in this study were most frequently taken in brackish water. It is believed that estuaries are the primary nursery grounds of young striper. (Rathjen & Miller, 1957)

Juvenile stripers grow very quickly in their nursery habitat. They feed principally upon marine worms and crustaceans. (Raney, 1952) Bigelow and Schroeder (1953) state that striper fry in Gulf of Maine rivers average 2 to 3 inches in length during their first winter. Raney (1958) states that most stripers are 4-5" by the end of their first year. By the time they are 2 years old, stripers are approximately 8 1/2". (Raney, 1958)

It is not until stripers are 2 years that they leave their estuarine homes and engage upon coastal migrations. (B & S) (Merriman, 1941) While in the ocean growth is fast. During their third year stripers grow from 40 cm to 46 cm. During their fourth year they attain 53 cm. (Merriman, 1937)

D. 7 Atlantic Sturgeon, *Acipenser oxyrhynchus*

Atlantic sturgeon spawn in coastal streams, ranging from the Gulf of St. Lawrence to the Gulf of Mexico (B & S, 1953) Females begin spawning when they are 13 or 14 years old; they may not spawn every year. (Dees, 1961) Males become sexually mature at age 9 or 10.

Spawning occurs in the spring or summer when water temperatures are 12.8 to 21.1°C (Dees, 1961) Vladykov et al (1963) noted that in 1925 spawning in the Delaware River occurred when water temperatures ranged from 13.3 to 17.8°C. In the Hudson River the spawning run takes place during late April and May. (Dees, 1961) In the rivers of the Gulf of Maine sturgeon ascend during May and June. (B & S, 1953) (Dees, 1961)

Little information is available concerning the physical and chemical requirements for the successful spawning of sturgeon. *Acipenser oxyrhynchus* spawn in rivers beyond the reach of tides. (Dees, 1961) (B & S, 1953) Bigelow and Schroeder (1953) cite evidence that sturgeon may occassionally spawn in brackish water. Spawning occurs in waters up to 10 feet in depth, and over bottoms of small rubble or gravel. (Dees, 1961) Vladykov et al (1963) reported that sturgeon spawn in the Delaware River over a hard clay bottom.

Sturgeon are a very prolific fish. Females produce between 800,000 and 2 1/2 million eggs (Vladykov, 1963) (B & S, 1953) (Dees, 1961) Eggs are scattered over a wide area, and no prenatal care is evident (V.D., 1963) The eggs are demersal and adhesive, becoming attached to stones, sticks and vegetation. (Dees, 1961) (V.D., 1963) Incubation requires 3 to 7 days, larvae are 13 mm upon hatching. (Dees, 1961) Vladykov et al (1963) state that sturgeon eggs hatch in 1 week at 17.8°C.

Juvenile sturgeon spend 1 to 3 years in their natal rivers before venturing into the ocean. They spend these first few years in the lower tidal reaches of the river. (Dees, 1961) Sturgeon attain 4-5 1/2 inches after their first two months of growth. (B & S, 1953) At 3 or 4 years of age, sturgeon have grown to 2 1/2 to 3 feet in length. (B & S) Juvenile sturgeon are able to grow in salt water estuaries, as sturgeon "a few inches long" have been taken in the St. Lawrence Estuary. (B & S) Juveniles 5 to 6 inches long have also been taken from the mouth of the Delaware River (B & S)

Sturgeon go to sea at various ages. In the Hudson River, juveniles have been known to remain until 8 years of age.

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APPENDIX E

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